# DEVELOPING HOMOGENEOUS SEQUENCES OF RIVER FLOWS AND PERFORMING COMPARATIVE ANALYSES OF FLOW CHARACTERISTICS

A Dissertation

by

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## ABSTRACT

The objectives of the dissertation research are (1) to improve and expand capabilities for developing naturalized or otherwise homogenous river flows representing specified conditions of basin development for input to models for simulating river/reservoir system management and (2) to investigate characteristics of observed, naturalized, and simulated regulated river flows of relevance to water management, especially integration of environmental flow standards in water management in Texas. Key research results and conclusions are as follows:

SWAT was applied to the Sabine, Neches, and GSA River Basins to develop daily and monthly natural-condition flows at relevant sites from available rainfall records. Alternative calibration strategies were developed, tested, and compared. SWAT was combined with the maintenance of variance method, type 2, called MOVE2, to develop a new methodology for filling in gaps of missing naturalized monthly flows. Comparative testing of alternative variations of flow synthesis methods was performed.

The drainage area ratio method for transferring flows for gauged to ungauged sites was investigated and an alternative more refined method proposed. A comparative assessment of alternative methods for transferring flows is presented using available flow data. The drainage area ratio method is shown to be inaccurate for very small or very large drainage area ratios.

SWAT was applied to develop daily flow pattern hydrographs for the Sabine, Neches, and GSA WAMs for use in disaggregating monthly naturalized flows to daily. Various issues were resolved and the daily pattern hydrographs were implemented in the WAMs. Rainfall-runoff modeling with SWAT is demonstrated to be a feasible approach for developing daily pattern hydrographs for the WRAP/WAM models and complexities are explored.

The Dundee Hydrological Regime Alteration Method (DHRAM), which incorporates the Indicators of Hydrologic Alteration (IHA) methodology, was applied to assess the hydrological alterations of daily river flow sequences between user-defined impacted and un-impacted periods in the case study river systems. Frequency metrics for

regulated versus naturalized flows from the WAMs are compared to assess long-term changes in flow characteristics.

Changes in flow characteristics range from being negligible at some sites to very large at other sites. Frequency analysis of unappropriated flows resulting from WAM simulations with versus without Senate Bill (SB3) instream flow standards were performed to evaluate the impacts of the environmental flow standards on water availability. Impacts on unappropriated flows range from no impacts at some sites to very significant impacts at other sites.

DEDICATION

To my beloved wife, Jiyoung Kim, and our sons, Seungu and Seungwan

and to well-beloved my parents, Bunja Woo and Heeki Ryu

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# CHAPTER I
# INTRODUCTION

Many river/reservoir system management models are reported in the literature and applied by researchers and practitioners worldwide. These models simulate reservoir/river system operations for flood control, water supply, hydropower generation, navigation, recreation, and maintenance of environmental flows. Incorporation of environmental flow considerations in river system management and associated modeling has been growing in importance in recent years in Texas and throughout the world. Input datasets for these computer simulation models include homogeneous sequences of stream flows, representing natural undeveloped conditions or other specified conditions of water resources development, regulation, and use. The stream flow input datasets capture the hydrologic characteristics of a river basin, including severe multiple-year droughts, major floods, and the full range of more normal flow fluctuations. The results of the simulation computations performed by the models include river flows representing another specified scenario of water development, regulation, and use of interest to water managers.

This research combines databases and computational techniques provided by the Texas Water Availability Modeling (WAM) System and Soil and Water Assessment Tool (SWAT) to investigate and improve capabilities for developing and analyzing long (50 years or greater) sequences of homogenous river flows at multiple sites in major river/reservoir systems that represent either natural or specified conditions of river basin development. The WAM System, maintained by the Texas Commission on Environmental Quality (TCEQ), consists of the generalized Water Rights Analysis Package (WRAP) modeling system and WRAP input datasets for the 15 major river basins and eight coastal basins of Texas. The SWAT watershed modeling system develops stream flow sequences based on datasets of precipitation and watershed parameters.

Homogeneous sequences of river flows are fundamental input required for simulating management of river/reservoir systems with WRAP or the many other available river/reservoir system models. The WRAP/WAM and SWAT modeling systems provide extensive datasets and simulation capabilities providing opportunities to improve and expand capabilities for generating river flow datasets that have broad applicability for other modeling systems as well as improving the WRAP/WAM system.

The research investigates: (1) methods for developing naturalized or otherwise homogenous river flows for input to models for simulating river/reservoir system operations and (2) characteristics of observed, naturalized, and simulated regulated river flows of relevance to water management and modeling thereof. This research on stream flow synthesis and analysis is applicable to all aspects of river/reservoir system management but focuses particularly on integrating environmental instream flow standards in comprehensive water management. The research deals with sequences of monthly and daily flows extending over several decades. The flows of interest are:

- observed actual flows recorded at stream gauging stations
- naturalized flows representing natural river basin conditions without water resources development, regulation, and use
- regulated flows computed in a simulation model representing a specified condition of water resources development, regulation, and use

## 1.1 Background

River and reservoir system analysis models, such as the WRAP/WAM modeling system, start with homogeneous sequences of monthly or daily stream flow volumes covering a hydrologic period-of-analysis at relevant sites. *Homogeneous* means that the flows represent a specified uniform condition of watershed and river system development, long-term climate, and water use. Non-homogeneities in historical gauged stream flows are typically caused primarily by construction of reservoir projects, growth or changes in water use, and other changes in water management practices over time. However, watershed land use changes, climate changes, and other factors may also affect the stationarity of recorded stream flow measurements.

The stream flows in the TCEQ WAM System WRAP input datasets are naturalized flows representing natural hydrology unaffected by the water resources development and management activities reflected in the WRAP water rights input datasets. Other terms for naturalized flows found in literature include unregulated, unimpaired, or virgin flows. Alternatively, stream flow inflows input to a river/reservoir system simulation model may represent some other specified homogeneous condition of river basin development. The basic concept is to provide a homogeneous set of flows as model input representing hydrology for a specified set of conditions.

The following aspects of the TCEQ WAM System are particularly relevant to this discussion regarding motivation for the dissertation research:

- The datasets for the individual river basins in the TCEQ WAM System include naturalized monthly flows at a total of about 500 sites, most of which are stream gauging stations. Past observed flows were adjusted by consultants working for the TCEQ during 1997-2000 to remove non-homogeneities caused by human activities at these 500 primary control points.
- These monthly flow sequences at the 500 control points are distributed to over 12,000 other ungauged control points within the WRAP simulations.
- The original TCEQ WAM System datasets include naturalized monthly flows covering hydrologic periods-of-analysis beginning in most cases in 1940 and in all cases between 1934 and 1945. The datasets extend through either 1989, 1996, 1997, 1998, or 2000. The datasets have not been updated due to the difficulty and expense of developing naturalized flows. However, the flow datasets for six case study river basins have been updated by extending the flows through 2013 based on precipitation datasets in research studies at Texas A&M University sponsored by the TCEQ, but the hydrology extensions have not been officially adopted by the TCEQ for the WAM System.
- Establishment of environmental flow standards has driven recent expansions of WRAP and the WAM System. Motivated by expanded needs for modeling sophisticated environmental flow requirements, a daily WRAP modeling system has recently been developed that includes disaggregating monthly flows to daily and flow forecasting and routing.

Historical flows observed at gauging stations are adjusted to develop flow sequences representing natural undeveloped conditions. This requires appropriate methodologies and typically much time and effort. For highly developed river systems, the adjustments to gauged flows to develop naturalized flows may involve significant approximations. Water use data is typically incomplete and approximate. Flow travel times and the effects of seepage, evapotranspiration, and other unmeasured channel losses during the downstream propagation of the effects of diversions, return flows, and reservoir operations are difficult to determine. Stream gauging stations have fixed periods-of-record and often have periods of missing data. The U.S. Geological Survey has discontinued operation of a significant number of gauging stations. Models include a great number of sites that have never been gauged.

The adjustments to gauged flows in the flow naturalization process for essentially all of the TCEQ WAM System hydrology datasets included adjustments for large recorded diversions from surface water sources, return flows from diversions from both ground water and surface water sources, and reservoir evaporation, storage, and releases. Some WAM datasets also include adjustments for spring flows affected by groundwater use. At least one WAM dataset includes naturalized flows reflecting adjustments for land use changes. Numerous relatively small reservoirs, diversions, and return flows were omitted in the flow adjustment process.

Although there are various methods to fill in gaps of missing data, the missing data in the WAM datasets were mainly filled with synthetic data made by linear regression based on flow data sequences for the same periods at gauged sites. In many cases, two or three flow data sequences at gauged sites would be used to fill in gaps of missing data due to the data discontinuation of a significant number of stream gauging stations, and poorly correlated data sequence would be used because there is no highly correlated data sequences around the site that has missing data.

The monthly naturalized flow sequences are distributed to over 12,000 other ungauged control points within the WRAP simulation. The WRAP simulation includes three alternative methods to synthesize the flow sequences at ungagged sites based on the flow sequences at gauged site (Wurbs, 2006). The drainage area ratio (DAR) methods with or without channel losses are usually used to synthesize the monthly naturalized flow sequences at ungauged sites (secondary control points) based on gauged sites (primary control points). The DAR method is widely used as a linear transfer method throughout the world, but it may lead to bias in the synthesized flow sequences at ungauged sites depending on the drainage area ratio. Thus, methods for removing bias in the DAR method and alternative methodologies have been reported in the literature.

Daily naturalized flow sequences are required for the daily version of the modeling system. Capabilities have been added to WRAP to disaggregate monthly naturalized flows to daily while preserving the monthly volumes based on daily flow pattern hydrographs. Hydrographs of daily flows adopted to define daily flow patterns could be unadjusted observed flows measured at gauging stations, daily gauged flows adjusted to remove the effects of human activity, or daily flows synthesized with a watershed rainfall-runoff model such as SWAT. The research explores situations in which each of these strategies is most appropriate.

Watershed precipitation-runoff models such as SWAT can be applied in alternative ways to accomplish various tasks in developing naturalized flow datasets. SWAT is combined in this research with modeling techniques included in WRAP to assess existing methods and develop expanded capabilities for developing naturalized monthly and daily flows. The applications of the SWAT precipitation-runoff modeling system investigated in the research include:

- synthesizing monthly and daily naturalized flows
- extending the period covered by the existing monthly naturalized flow sequences
- filling in gaps of missing naturalized flows
- synthesizing flows at ungauged sites based on existing naturalized flows at gauging stations
- disaggregating monthly naturalized flows to daily

The daily WRAP modeling system has been recently developed to support incorporation of environmental flow standards into the WAM system. Disaggregation of monthly naturalized flows to daily is a major focus of the proposed research. Other aspects of analyzing stream flows in support of environmental flow studies are also important. Flow analysis methods are important both in establishing environment flow standards and evaluating the extent to which environmental flow standards can be achieved subject to stream flow availability.

Many rivers have been intensively developed for human requirements without consideration of the various negative impacts on river ecosystems during the last century around the world. This has been driven by population and economic growth in many countries. The extensive ecological degradation and loss of biological diversity resulting from river exploitation have been eliciting widespread concern for conservation and restoration of healthy river ecosystems for several decades among many developed countries (Poff *et al.* 1997). Society is now looking for the balance between economic and ecologic values. Furthermore, the allocation of environmental flow has become a fundamental paradigm in operation and management of a river system. Thus, environmental flow requirements are now legitimately recognized and addressed by establishing standards or related laws in many countries (Sophocleous, 2007).

Scientists face the challenge of how to assess and mitigate the impacts of human activities on river flows and establish and update environmental flow standards under current and future water use conditions. River/reservoir system models provide capabilities for evaluating long-term alterations in river flows. The following modeling and analysis components are essential to addressing the challenge of incorporating environmental flow standards in integrated water management:

- long-term naturalized flow sequences at sites of interest
- river/reservoir system models that incorporate various water management/use scenarios
- environmental flow standards
- strategies to quantify the mitigation effects achieved by environmental flow standards

## 1.2 Water Availability Modeling (WAM) System

The TCEQ WAM System consists of the WRAP generalized river/reservoir system simulation modeling system developed at Texas A&M University over the past two decades and 20 WRAP input datasets for the 23 river basins of Texas shown in Figure 1.1 originally developed during 1997-2001 by consulting firms working for the TCEQ (Wurbs, 2005). The monthly WRAP/WAM System is routinely applied in administration of the water right permit system and in regional and statewide planning (Wurbs, 2014). Expansion of WRAP and WAM capabilities over the past several years has been motivated largely by environmental flow standards established pursuant to the 2007 Senate Bill 3 (Wurbs and Hoffpauir 2013b). Research and development in expanding the WRAP/WAM System is currently focused on implementing the daily modeling system and integrating environmental flow standards.

### 1.2.1 WAM Datasets

The 20 WAM datasets covering the 15 major river basins and eight coastal basins of Texas include water rights, other water allocation mechanisms, and other constructed facilities. The hydrologic data include monthly naturalized flow sequences at primary (gauged) control points and net reservoir evaporation-precipitation depths. Periods covered by the monthly hydrologic data are typically from 1940s through late 1990s. WRAP includes methods for generating the hydrologic data at the secondary (ungauged) control points based on flows at the primary control points.

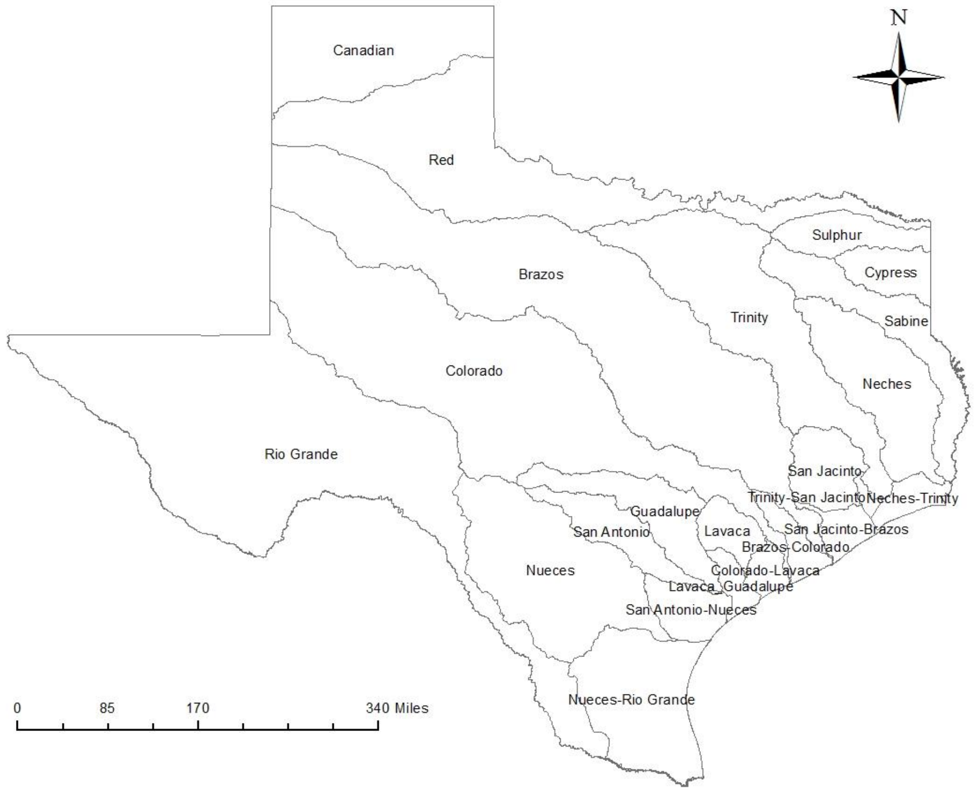



Figure 1.1 WAM System River Basins

There are datasets for two alternative water management scenarios each river basin reflecting combinations of premise regarding water use, return flows, and reservoir sedimentation. The premises of the full authorization scenario are as follows (Wurbs, 2005):

- Water use targets are set at the full amount authorized by the permits.
- Full reuse with no return flows is assumed.
- Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation.
- Term permits are not included

The premises of the current conditions scenario are as follows (Wurbs, 2005):

- The water use target for each water right is set based on the maximum annual amount actually use in any year during a recent 10-year period.
- Best estimates of actual return flows are adopted.
- Reservoir storage capacities and elevation-area-volume relationships for major reservoirs are adjusted to reflect year 2000 conditions of sedimentation.
- Term permits are included.

The TCEQ uses the full authorization scenario in the evaluation of new permanent water right permit or amendments to existing permanent water right permits and the current conditions scenario in the evaluation of term permit application. The period of record, number of primary and total control points, number of water right and instream flow right records, and number of reservoirs in each scenario are listed in Tables 1.1 and 1.2 respectively.

Table 1.1 Texas WAM system Full Authorization Scenario Datasets

| Map NO. | River Basin | Original Period of Record | Number Primary Control Points | Total Number Control Points | Model Water Rights (WR/IF) | Model Reservoirs |
|---|---|---|---|---|---|---|
| 1 | Canadian River Basin | 1948-98 | 12 | 85 | 50/0 | 47 |
| 2 | Red River Basin | 1948-98 | 47 | 447 | 489/103 | 245 |
| 3 | Sulphur River Basin | 1940-96 | 8 | 83 | 85/5 | 53 |
| 4 | Cypress Bayou Basin | 1948-98 | 10 | 189 | 163/1 | 91 |
| 5 | Rio Grande Basin | 1940-00 | 55 | 957 | 2,584/4 | 113 |
| 6 | Colorado River Basin and Brazos-Colorado Coastal | 1940-98 | 45 | 2,395 | 1,922/86 | 511 |
| 7 | Brazos River Basin and San Jacinto-Brazos Coastal | 1940-97 | 77 | 3,842 | 1,634/122 | 678 |
| 8 | Trinity River Basin | 1940-96 | 40 | 1,334 | 1,169/23 | 703 |

Table 1.1 (Continued)

| Map NO. | River Basin | Original Period of Record | Number Primary Control Points | Total Number Control Points | Model Water Rights (WR/IF) | Model Reservoirs |
|---|---|---|---|---|---|---|
| 9 | Neches River Basin | 1940-96 | 20 | 318 | 333/17 | 176 |
| 10 | Sabine River Basin | 1940-98 | 27 | 376 | 310/21 | 207 |
| 11 | Nueces River Basin | 1934-96 | 41 | 542 | 373/30 | 121 |
| 12 | Guadalupe and San Antonio River Basins | 1934-89 | 46 | 1,349 | 360/184 | 237 |
| 13 | Lavaca River Basin | 1940-96 | 7 | 185 | 71/30 | 22 |
| 14 | San Jacito River Basin | 1940-96 | 16 | 411 | 148/13 | 114 |
| 15 | Nueces- Rio Grande | 1948-98 | 29 | 200 | 104/8 | 64 |
| 16 | San Antonio-Nueces | 1948-98 | 9 | 53 | 12/2 | 9 |
| 17 | Lava-Guadalupe Coastal | 1940-96 | 2 | 68 | 10/0 | 0 |
| 18 | Colorado-Lavaca Coastal | 1940-96 | 1 | 111 | 27/4 | 8 |
| 19 | Trinity-San Jacinto | 1940-96 | 2 | 94 | 24/0 | 13 |
| 20 | Neches-Trinity Coastal | 1940-96 | 4 | 245 | 138/9 | 31 |

Table 1.2 Texas WAM System Current Condition Scenario Datasets

| Map NO. | River Basin | Original Period of Record | Number Primary Control Points | Total Number Control Points | Model Water Rights (WR/IF) | Model Reservoirs |
|---|---|---|---|---|---|---|
| 1 | Canadian River Basin | 1948-98 | 12 | 85 | 56/0 | 47 |
| 2 | Red River Basin | 1948-98 | 47 | 450 | 486/110 | 246 |
| 3 | Sulphur River Basin | 1940-96 | 8 | 83 | 85/5 | 53 |
| 4 | Cypress Bayou Basin | 1948-98 | 10 | 189 | 159/1 | 91 |
| 5 | Rio Grande Basin | 1940-00 | 55 | 957 | 2,594/4 | 113 |
| 6 | Colorado River Basin and Brazos-Colorado Coastal | 1940-98 | 45 | 2,396 | 1,928/93 | 510 |
| 7 | Brazos River Basin and San Jacinto-Brazos Coastal | 1940-97 | 77 | 3,852 | 1,734/145 | 711 |

Table 1.2 (Continued)

| Map NO. | River Basin | Original Period of Record | Number Primary Control Points | Total Number Control Points | Model Water Rights (WR/IF) | Model Reservoirs |
|---|---|---|---|---|---|---|
| 8 | Trinity River Basin | 1940-96 | 40 | 1,338 | 1,190/35 | 709 |
| 9 | Neches River Basin | 1940-96 | 20 | 318 | 317/21 | 198 |
| 10 | Sabine River Basin | 1940-98 | 27 | 375 | 314/21 | 206 |
| 11 | Nueces River Basin | 1934-96 | 41 | 545 | 392/32 | 125 |
| 12 | Guadalupe and San Antonio River Basins | 1934-89 | 46 | 1,352 | 879/202 | 243 |
| 13 | Lavaca River Basin | 1940-96 | 7 | 184 | 68/30 | 21 |
| 14 | San Jacito River Basin | 1940-96 | 16 | 413 | 156/15 | 114 |
| 15 | Nueces- Rio Grande | 1948-98 | 29 | 200 | 109/8 | 65 |
| 16 | San Antonio-Nueces | 1948-98 | 9 | 53 | 12/2 | 9 |
| 17 | Lava-Guadalupe Coastal | 1940-96 | 2 | 68 | 12/0 | 0 |
| 18 | Colorado-Lavaca Coastal | 1940-96 | 1 | 111 | 27/4 | 8 |
| 19 | Trinity-San Jacinto | 1940-96 | 2 | 94 | 26/1 | 13 |
| 20 | Neches-Trinity Coastal | 1940-96 | 4 | 245 | 138/9 | 31 |

### 1.2.2 WRAP Modeling System

WRAP is a generalized river/reservoir simulation modeling system that simulates the development, management, regulation, allocation, and use of the water resources of a river basin or multiple-basin region. Hydrologic and institutional water availability and reliability for water supply diversion, environmental instream flows, hydroelectric energy generation, and reservoir storage can be assessed by WRAP. WRAP models basin-wide interactions among a great number of water users and diverse water management facilities and practices under a variety of water allocation arrangements.

The WRAP modeling system produces sequences of naturalized flows, regulated flows, unappropriated flows, reservoir storage, reservoir net evaporation volumes, incremental change in channel reach losses, water supply diversions, hydroelectric power generated, and other quantities. Simulation results are summarized with frequency statistics and reliability indices and used for planning and water right regulatory applications.

The newer version of the WRAP modeling system includes features that are currently being implemented as well as capabilities that are routinely applied by agencies and consulting firms in Texas. The TCEQ WAM website provides WRAP input datasets. The WRAP software and documentation are available at http://ceprofs.tamu.edu/wurbs/wrap.htm.

The WAM system was originally implemented by the TCEQ, Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), and their contractors which consist of two universities and 10 consulting engineering firms pursuant to comprehensive water management legislation enacted by the Texas Legislature in 1997 (Wurbs, 2005) and continues to be maintained by the TCEQ. Applicants or their consultants apply the modeling system in the preparation of water right permit applications, and the TCEQ staffs apply the modeling system in the evaluation of permit applications. The TWDB applies the model to establish regional and statewide water management plans. River authorities and other water management entities also take advantage of the WAM system in endeavors not directly mandated by the TCEQ water right permitting or TWDB planning programs.

Environmental flows have been a key issue in water management and development in Texas for the last several decades. The Texas Instream Flow Program authorized by SB2 enacted by the Texas Legislature in 2001 and expanded by SB3 in 2007 is implemented joinly by the TCEQ, TWDB, and TPWD. The SB2 program includes scientific studies to decide flow conditions necessary for supporting a sustainable ecological environment in the river basins of Texas (TCEQ, TPWD, and TWDB 2008). Environmental instream flow requirements are defined within the framework of subsistence flows, bas flows, high flow pulses, and overbank flood events. The daily version of WRAP which is being further expanded to model high flow pulses and overbank flood evens was updated to address the issues of the environmental flow requirements (Wurbs and Hoffpauir, 2013b).

## 1.3 SWAT Modeling System

The Soil and Water Assessment Tool (SWAT) is one of several available generalized watershed models that simulate the hydrologic processes that convert precipitation to stream flow (Singh and Frevert, 2006). SWAT is a public domain computer model developed jointly by the U.S. Department of Agriculture (USDA) Agriculture Research Service and Texas A&M AgriLife Research. The software, user documentation (Neitsch *et al*., 2011; Arnold *et al*., 2012a), and a variety of other relevant publications are available at the SWAT website: http://swat.tamu.edu/.

SWAT is designed to simulate rainfall-runoff processes and associated erosion, sedimentation, and water quality processes at scales ranging from small watersheds to large river basins. The modeling system has been extensively applied to evaluate the effects of land use, agricultural practices, other land management practices, and other factors on the quantity and quality of watershed runoff in river basins throughout the United States and abroad.

SWAT is a physically-based, semi-distributed, continuous-simulation, daily rainfall-runoff model. SWAT simulates river basin hydrology for each day of a long period that may extend over many years based on rainfall and other input data characterizing climate, land cover, soil, and other watershed conditions. The modeling system provides options for automatically producing parameter values from geographical information system (GIS) data such as digital elevation models (DEMs) and soil and land cover databases. Hydrological response units (HRUs) are the basic computational units in SWAT. The model divides a watershed into subbasins and further divides a subbasin into homogeneous spatial units, called HRUs, characterized by similar soil, land cover, and topographical conditions.

Sequences of daily rainfall at rain gauge sites are provided as input. The SWAT weather generator can be applied to automatically generate daily rainfall and other weather data. Periods of missing rainfall data can be synthesized with the weather generator. The model uses climate data from the rainfall and weather gauge station that is nearest to the centroid of each subbasin. Surface runoff from daily rainfall is calculated by the Natural

Resources Conservation Service (NRCS) curve number method based upon soil, land cover, and antecedent rainfall conditions. Base flows are computed from the interaction among surface, subsurface, and ground water. The surface runoff in a HRU is routed through the river system within a subbasin using the Manning equation. The surface runoff from a subbasin is routed through channels to an outlet point using the variable storage or Muskingum hydrologic routing methods.

SWAT considers various natural hydrologic losses such as evapotranspiration, transmission losses, and infiltration. The model calculates evaporation from soil and transpiration from plants separately. Actual soil evaporation is calculated from exponential functions of soil depth and water content. Plant transpiration is computed by using a linear function of potential evapotranspiration and leaf area index.

Digital elevation model (DEM) data is used by SWAT to delineate watersheds and estimate topographic parameters such as channel length, channel slope, and overland slope. DEM data at a 30-meter resolution can be obtained from the Natural Resources Conservation Service (NRCS) Data Gateway website (http://datagateway.nrcs.usda.gov/).

Land cover data necessary for calculating NRCS curve numbers are also obtained from the NRCS Data Gateway website. SWAT uses the general soil map for the United States (STATSGO) to estimate NRCS curve numbers, interaction characteristics between surface and subsurface water, and geological parameters. These data were developed in 1995 and updated in 2006 by the NRCS. The data noted in this paragraph are used in SWAT to determine HRUs.

SWAT applications reported in the literature could be broadly defined as hydrologic only, hydrologic and pollutant loss, or pollutant loss only assessment (Gassman *et al.*, 2007). Hydrologic assessment and prediction are fundamental for all SWAT watershed applications. These applications have performed with some type of graphical and/or statistical calibration and validation for an interest watershed. The regression correlation coefficient ($R^2$) and the Nash-Stucliffe model efficiency (NSE) coefficient (Nash and Stucliffe, 1970) are most widely used for hydrologic calibration and validation.

SWAT produced reasonable results in the simulation of runoff on a daily, monthly, and annual basis in various basins, however, it is clear that poor results have resulted in parts or all of some studies (Gassman *et al.*, 2007). Inadequate representation of rainfall inputs, due to either a lack of adequate rain gauges in the simulated watershed or subwatershed configurations that were too coarse to capture the spatial detail of rainfall inputs, may lead to poor results for the SWAT model (Gassman *et al.*, 2007). Thus, if there are appropriate rainfall data which are well spatially distributed in the simulated watershed, SWAT model can provide reasonable hydrologic simulation results.

## 1.4 Literature Review

Key topics are reviewed and related references are cited in the following discussion prior to outlining the research methodology in the last section of this introductory Chapter I.

### 1.4.1 Naturalized Flow

Naturalized flows represent flows in a river that would have historically occurred exclusive of human influences, that is, without the occurrence of upstream reservoir operations, diversions, and return flows (TNRCC, 1997). Naturalized flows represent natural hydrology unaffected by any human influences such as water resources development and management (Wurbs, 2013a). Alternative terms for naturalized flows are unregulated, virgin, and unimpaired flows. Homogeneous means that the flows represent a specified uniform condition of watershed and river system development, long-term climate, and water use. Naturalized flow datasets have been typically developed with two difference methods: (1) adjusting recorded flows at gauging stations to remove the past impacts of upstream major reservoirs, water supply diversions, return flows from surface and ground water sources, and possibly other factor and (2) synthesizing the datasets from precipitation data with a watershed precipitation-runoff model. Adjusting gauged flows to remove hydrologic effects of human activities is generally more accurate than synthesizing flows with a watershed model (Wurbs, 2013a).

There are few cases reported in the published literature in which naturalized flows have been developed for establishing a very large database like the TCEQ WAM System datasets, probably because these require tremendous time, effort, and funding (Kim and Wurbs, 2010). Monthly naturalized streamflow datasets had been developed for establishing a database of updated streamflow data from 1931 to 2001 for 35 sites in the Red River of the North Basin (Emerson, 2005). These are the recorded data for the entire data-development period for 4 sites, partially recorded data for 10 sites, and no gauged data for 21 sites. Thus, data transfer methods such as a modified drainage area ratio, a maintenance of variance extension type 1, and a water-balance method were used for filling in gaps of missing data and generating synthetic data at ungauged sites based on gauged sites. Naik and Jay (2005) developed monthly virgin flow sequence by adjusting irrigation depletion from the river from 1879 to 1928 at the Dalles station in the Columbia River Basin. Monthly irrigation depletion was estimated based on the irrigation area and a correction factor.

Naturalized flow data have been developed in studies reported in the literature at one or two sites to evaluate regulated effects by human influence such as a dam, diversion, and return flows or to assess the flow records in rivers. The monthly naturalized flows (1883-1992) for the River Thames in the United Kingdom have been developed for assessing the monthly flow record using a unit hydrograph model with effective rainfall (Littlewood and Marsh, 1996). Daily naturalized flow data at two sites (up and downstream) in Peace River in Canada during 1972 to 1996 were developed for evaluating the regulation effects by the W.A.C. Bennett hydroelectric dam using daily recorded data for a upstream site and a hydraulic models for a downstream site (Peters and Prowse, 2001). Daily naturalized flow sequence (1987-2000) at a point in the Han River, South Korea was constructed for evaluating the effects of flow regulation by two major multipurpose dams, Soyangan and Chungju Dams, on the flow regime using SWAT model (Kim et al, 2012). In these cases, precipitation-runoff models were mostly used.

The methodology for developing naturalize flow dataset for the WAM system was established by the Texas Natural Resources Conservation Commission (TNRCC) (renamed TCEQ in 2003) in 1997 and was published as WAM Technical Paper #1. In this research, the TNRCC recommended the traditional methodology to determine naturalized flow through comparing three different methodologies. The general equation for calculating naturalized flow is:

$$\mathrm{NF} = \mathrm{GF} + D_h - RF_h + S_h + E_h \tag{1.1}$$

Where, NF is naturalize flow, GF is gauged flows, $D_h$ is diversions, $RF_h$ is return flows, $S_h$ is storage change in a reservoir, and $E_h$ is evaporation.

Naturalized flow files are included in the 20 Texas WAM system datasets available at the WAM web site maintained by the TCEQ (Wurbs, 2005). Consulting engineering companies contracted with TCEQ to construct the WAM datasets with the methodology noted above during 1998-2004 (Wurbs, 2005). The naturalized flow datasets were generally constructed by adjusting recorded data at gauge stations. Gaps of missing data were filled by linear regression based on recorded data at adjacent sites at the same period (Wurbs, 2013a).

Considerable time and effort were required to develop the original long-term sequences of monthly naturalized flows. Updating the datasets to the present time also requires time and costs (Kim and Wurbs, 2010). A hydrologic model (Wurbs, 2013b) for updating the naturalized flow datasets to present using monthly precipitation and reservoir evaporation databases maintained by the Texas Water Development Board (TWDB) was recently developed and applied to update the WAM datasets for the Brazos, Trinity, Colorado, GSA, Neches, and Sabine River Basins.

### 1.4.2 Methodologies to Fill in Gaps of Missing Naturalized Flows

Filling in gaps of missing data is an important task in developing the sequences of monthly naturalized flows. However, WRAP does not include a routine to assist with this task, though WRAP has options to develop sequences of naturalized flows at gauging stations and to distribute naturalized flows from gauged to ungauged locations (Wurbs, 2013a). There are two typical problems in dealing with discontinuous streamflow data. The first is to select appropriate transfer methods or techniques, and the second is to select donor stations having a strong correlation with partially recorded data at a target station. The most widely used transfer method of data infilling is linear regression assuming homogeneity (Khalil *et al.* 1998). The linear regression method cannot preserve any particular statistical characteristics of the recorded data while it can provide the best estimate (minimum square error) for each individual streamflow values (Hirsch 1982). To address this problem of the linear regression approach, Hirsch (1982) suggested two different techniques, called maintenance of variance extension type 1 and 2, MOVE1 and MOVE2. These techniques are widely used for reconstructing flow sequences or filling in gaps of missing data.

However, these linear regression models cannot consider seasonality in hydrological data and heterogeneous relationship between both recorded data. These problems have led to the development of transfer techniques that consider relationships among heterogeneous groups of observations (Khalil *et al.* 1998). Time-series methods were suggested as an alternative to linear regression methods through comparison of both methods (Beauchamp *et al.*, 1989). A group-based approach that treats flow data as groups rather than as single-valued records with the techniques mentioned above was proposed for estimating missing values when data are significantly auto-correlated like naturalized flows (Elshorbagy *et al.*, 2000). Khalil *et al.* (1998) proved that the group-based neural network models may infill the missing peak flows and also the moderate flows in retaining relevant properties of the historical streamflow both at the auto-and cross-variate series levels. However, these models have not been widely used due to their complexity, difficulties in application, and the same problem as linear models.

Selecting a donor station with long continuous streamflow records is more important than selecting transfer methods in filling in gaps of missing data in flow sequences (Hirsch 1979 and Harvey *et al.* 2012). This is because missing data at a target station should be filled based on a source of information, temporal variability and hydrologic extremes, of donor stations (Hirsch 1979). However, scientists often face the problem that base stations highly correlated with a target station do not exist around a target station in reality.

### 1.4.3 Development of Naturalized Flows at Ungauged Sites Based on Flows at Gauged Sites

As WRAP input datasets include sequences of monthly naturalized flows at about 12,400 ungauged sites that are estimated based on the sequences at 500 gauged sites, the accurate synthesizing of naturalized flows at ungauged sites is a difficult challenge (Wurbs, 2006). The WRAP modeling system includes the following three flow distribution methods: (1) drainage area ratio (DAR), (2) modified Natural Resources Conservation Service (NRCS) curve-number based method (NRCS CN method), and (3) a generic equation. Of the three methods, the NRCS CN method was originally recommended as the default (Wurbs, 2006). However, due to difficulties in accurately estimating curve numbers, the DAR method with or without considering channel losses is commonly used in applications of the Texas WAM System The NRCS CN method can calculate monthly flows at ungauged sites using the relationship between precipitation depth and runoff volumes determined by the ratio of drainage area, annual precipitation, and NRCS curve numbers at the both gauged and ungauged watersheds (Wurbs, 2006).

Nationwide and worldwide, the DAR may be the mostly widely used method for estimating flows at ungauged sties based on flows at gauged sites since no additional information other than the streamflow data at a gauged site and the drainage areas of the gauged and ungauged sites is required (Farmer and Vogel, 2013). However, the quality of synthetic flow sequences by the DAR method may be highly inaccurate if the drainage area ratio is not between about 0.3 and 1.5 (Ries and Friesz, 2000). In order to address this problem on the DAR method, the basic equation of the DAR had been modified with bias correction factor and exponent parameter as followings (Emerson et al, 2005):

$$Q_y = K\left(\frac{A_y}{A_x}\right)^{\phi} Q_x \qquad (1.2)$$

Where $Q_y$ is streamflow at an ungauged site, $Q_x$ is streamflow at a gauged site, $A_y$ is the drainage area of the ungauged site, $A_x$ is the drainage area of the gauged site, $K$ is a bias correction factor, and $\phi$ is an exponent parameter. The bias correction factor is estimated using the nonparametric method described by Duan (1983), and the exponent parameter is calculated by a regression equation between flow sequence and drainage area at a gauged site (Emerson et al, 2005).

Another approach is a regional statistical method for estimating flow sequences at an ungauged site based on the flows sequences at gauged sites suggested by Hirsch (1979), is called standardization with mean and standard deviation (SMS) by Farmer and Vogel (2013). SMS is based on hypothesizing that the standardized flows at both an ungauged and a gauged site are approximately equal, and can be expressed as:

$$\frac{Q_x-\mu_x}{\sigma_x} = \frac{Q_y-\mu_y}{\sigma_y} \tag{1.3}$$

Where, $Q$ is stream flow at each subscripted site, $\mu$ is mean at each subscripted site, and $\sigma$ is standard deviation at each subscripted site. Statistical parameters at gauged sites are extracted from recorded data, and statistical parameters at ungauged sites are estimated from regional regression equation between the statistical parameters of flow sequences and regional hydrologic features. Likewise, a streamflow transposition method using the standard deviation with beta coefficient and a regression formula was also proposed based on a linear regression equation without intercept (Gan et al, 1991).

### 1.4.4 Disaggregation of Monthly Flows to Daily

The disaggregation models have focused on space or time disaggregation and on annual to seasonal or seasonal to sub-seasonal flows (Kumar et al, 2000). These models are typically divided into parametric or nonparametric and stochastic or deterministic approaches at single or multiple sites (Acharya and Ryu, 2014). However, the stochastic approaches should be excluded in this research because disaggregated datasets from monthly to daily are required for a river/reservoir system simulation model.

Kumar *et al.* (2000) presented the disaggregation method for simultaneously disaggregating monthly to daily streamflows at a number of sites based on an index site using an optimization algorithm. Ganju *et al.* (2008) disaggregated monthly to daily streamflows for 1851-1929 by using the unimpaired flows for 1967 to 1987 that is closely related to the monthly hydrograph that will be subject to disaggregation for temporal downscaling of decadal sediment load estimates to a daily interval. A nonlinear deterministic approach to generate sequences of daily streamflows by taking account of streamflow sequences of successively doubled time resolutions between daily and 16 days were developed by Sivakumar *et al.* (2004). A simple method for streamflow disaggregation from monthly to daily at a target station by using a sources station that is selected based on minimum error criteria, which are calculated regarding to streamflow volume within a three-month time window was proposed by Achary and Ryu (2014). Although numerous methods, algorithms, and techniques have been developed at different times with modifications and improvements reported in the literature, disaggregation of streamflow from monthly to daily time steps is still a challenge. The major constraints consist of intensive computational resources, high dimensionality of the disaggregation problem, degree of feasibility to meet targets, and the uncertainty included in estimating parameters (Nowak *et al.*, 2010).

The monthly WRAP/WAM system was expanded to the daily version primarily to address the issues of the environmental flow requirements in Texas (Wurbs and Hoffpauir, 2013a). It is necessary to incorporate daily flow sequences into the daily simulation. Thus, monthly naturalized stream flows are converted to daily in the daily simulation based on daily flow pattern hydrographs while preserving the monthly volumes. The daily WRAP/WAP system has six options to disaggregate monthly datasets to daily datasets: (1) uniform distribution, (2) linear interpolation, (3) variability adjustment, (4) flow pattern, (5) drainage area ratio transfer, and (6) regression equation transfer (Wurbs and Hoffpauir, 2013a). The flow pattern option is generally used. Pattern Hydrographs have been derived from two alternative sources: (1) observed USGS daily flows, (2) computed unregulated daily flows from a USACE modeling system. For unregulated daily flows, the Fort Worth District of the U.S. Army Corps of Engineers (USACE) has developed reservoir operation models to support operations of USACE reservoirs.

### 1.4.5 Generalized River/Reservoir System Management Models

Numerous reservoir/river system models have been developed for analyzing river system development and management, and are described in the published literature. The models continue to be improved and expanded. Although there are many models used for general or specific purposes, this review concentrates on user-oriented generalized modeling systems. User-oriented implies that a model is designed for use by professional practitioners other than the model developers (Wurbs, 2012). Generalized means that a model is designed for applications to a range of concerns dealing with river systems of various configurations and locations, rather than being site-specific customized to a particular system (Wurbs, 2012).

The generalized models combining a specific scenario of water resources development, control, allocation, management, and use with a specific condition of historical river basin hydrology generally track the movement of water through a river system including various man-made river structures based on volume-balance. Historical river basin hydrology is represented by natural unregulated streamflow, and net reservoir surface evaporation-precipitation rates for each time step of a hydrologic period-of-analysis (Wurbs, 2012). The results of a simulation are expressed as reservoir storage and streamflow frequency statistics and water supply reliability metrics for establishing alterative management strategies and practices.

The four modeling systems, ResSim, MODSIM, WRAP, and RiverWare are widely applied in the United States, are also applied in other countries, providing a broad range of analysis capabilities, and are representative of the state-of-the-art from the perspective of practical applications dealing with complex river systems (Wurbs, 2012).

The Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE) revealed ResSim to the public in 2003. ResSim can simulate multi-purpose, multiple-reservoir systems for real-time decision support of USACE reservoir control personnel. The computational time-step can be selected by a user from 15 minutes to one day.

MODSIM is a generalized river/reservoir system model developed by Colorado State University (CSU) sponsored by United State Bureau of Reclamation (USBR). MODSIM has a graphical user interface and general framework for river/reservoir system modeling (Wurbs, 2012). A model user can select various time-step from monthly, weekly, and daily for various term planning, management, and operations.

The Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) of the University of Colorado sponsored by USBR and Tennessee Valley Authority (TVA) developed RiverWare. This model can calculate volume balance at reservoirs, hydrologic routing in river reaches, evaporation and other losses, diversions and return flows, and additionally provides optional features, groundwater interactions, water quality, and electric power economics with daily or hourly time-steps (Wurbs, 2012).

The WRAP modeling system (Wurbs 2013a and 2013b) adopted in the TCEQ WAM System and applied in this dissertation research is a generalized river/reservoir simulation modeling system that simulates the development, management, regulation, allocation, and use of the water resources of a river basin or multiple-basin region. Hydrologic and institutional water availability and reliability for water supply diversion, environmental instream flows, hydroelectric energy generation, and reservoir storage can be assessed by WRAP. WRAP may model basin-wide interactions among a great number water uses and diverse water management facilities and practices under a variety of water allocation arrangements. The WRAP modeling system can produce sequence of naturalized flows, regulated flows, unappropriated flows, reservoir storage, reservoir net evaporation volumes, incremental change in channel reach losses, water supply diversions, hydroelectric power generated, and other quantities using input datasets such as naturalized flows, net reservoir evaporation less precipitation rates adjusted for site runoff, and stream flow channel loss parameters. These results are summarized with frequency statistics and reliability indices.

### 1.4.6 Environmental Flow Standards

*Impacts of water resources development on stream flow*

Flow regime change is caused by a complex mix of drivers that include climate, topography, land cover, land use, and water resources developments, but water resources development projects such as the construction of dams, diversion of water supplies for agricultural, industrial, and municipal uses, and land use change have mainly led to serious alterations in rivers that may affect stream ecosystems (Vogl and Lopes, 2009). Water use has sharply increased due to population and economic growth during the last several decades worldwide. Even though the rate of increase recently tends to go down, it was expected that humans will appropriate 75% of the world's accessible surface water by 2025 (Postel *et al.*, 1996). Accordingly, water resources developments are still going on and will be continued due to social and economic requirements around the world. The main impacts by water resources developments on river hydrology represent frequency, magnitude, and shape: annual flood peak, annual flow through, annual flood volume, time to flood peak, flood drawdown time and interarrival time (Singer, 2006). Of the water resources developments, it has been well known that a dam is a representative structure that has great impacts on river hydrology.

The impacts by dams are representatively decreasing the frequency and magnitude of high flow events and stabilizing low flows (Vogl and Lopes, 2009). Peters and Prowse (2001) examined how much flow regulation affects alteration of downstream hydrographs. In their research, it was revealed that a hydroelectric facility and associated reservoir in the Peace River, Canada leads to significant changes to the river hydrograph at even some 1,100 km downstream through comparing the hydrologic characteristics of daily regulated and naturalized flows (Peters and Prowse, 2001). Dams have been found to significantly change hydrologic characteristics in rivers such as minimum and maximum flows through investigating pre- and post-dam hydrologic changes from dams across the United States (Magilligan and Nislow, 2005). Although it is obvious that dams affect flow regimes in rivers, the effect of scale is greatly dependent on the ratio of reservoir capacity to annual flow volume called impounded runoff index (Singer, 2006). These alterations have eventually led to an increase of habitat generalist fish species, a decrease of native obligate riverine fishes, and an overall homogenization of species assemblages (Vogl and Lopes, 2009).

Quantifying long-term changes in flow characteristics due to water resources development is challenging because river flow is very variable, its influencing factors are various, complex and interactive, and available recorded data are very limited.

*Environmental flow requirements*

Humans have expended great effort to control the dynamics of free-flowing waters for transportation, water supply, flood control, agriculture, and power generation (Poff et al, 1997). However, these efforts have led to extensive ecological degradation and loss of biological diversity, and many rivers could not provide socially valued native species or sustain healthy ecosystems. This recognition naturally led to the concern for conservation and restoration of healthy river ecosystems, and eventually the establishment of the science of environmental flow assessment for determining ecosystem conservation and resources protection. Furthermore, environmental requirement is now legitimately recognized and addressed by establishing standards or related laws in many countries (Sophocleous, 2007).

In the past, only water quantity (minimum flow) and quality were emphasized in the protection of river ecosystems. Environmental flows specified as constant minimum limits are still widely used as an environmental flow standard in many countries. Minimum flows in rivers and streams are specified for providing a certain level of protection for the aquatic environment (Jowett, 1997). However, it now recognized that environmental dynamism is required to restore and conserve native species diversity and ecological integrity in rivers and other ecosystems (Poff *et al.*, 1997). The natural flow regime is defined as the characteristic pattern of a river's flow quantity, timing, and variability, and can be identified from long-term gauged data (Poff *et al.*, 1997). The National Research Council (NRC, 2006) also recommended that the natural flow regime is a central concept to conserve and restore regulated rivers through environmental flow requirements. NRC developed a range of recommended flows for the low flows in each month, high flow pulse throughout the year, and floods with targeted inter-annual frequencies based on interdisciplinary and scientific process, and applied the process to the Savannah River, Georgia, USA (Richter *et al.*, 2006).

Tharme (2003) reviewed the status of environmental flow methodologies identifying some 207 individual methodologies, recorded for 44 countries within six world regions. In his research, environmental flow methodologies were classified into four types, namely hydrological, hydraulic rating, habitat simulation (or rating), and holistic methodologies (Tharme, 2003). Hydrological method uses hydrological data for establishing environmental flow as a percentage of average annual flow or as a percentile from the flow duration curve. Hydraulic rating methods are based on historical flow records and physical dimensions of a river for determining biotopes of a river. Habitat simulation is a methodology using a simulation model based on hydrological, hydraulic, and biological response data, and holistic methodologies are frameworks including all three methodologies (Tharme, 2003).

Protection of environmental instream flows in the river systems of Texas has been a concern in water resource planning, allocation, and management historically, particularly since the 1980's (Wurbs and Hoffpauir, 2013b). The scientific studies were implemented to determine flow conditions that are needed for supporting a sound ecological environment in the river basins of Texas according to SB2 program. A new regulatory approach for protecting environmental flows by the efforts of the state agencies, water managers, stakeholder groups, environmental organizations, and science and engineering community culminating in rules to be administered by the TCEQ was mandated by SB3 (Wurbs and Hoffpauir, 2013b).

Environmental flow standards consist of a set of flow metrics and rules that vary seasonally or by hydrologic condition and by location that govern decisions to curtail junior rights to divert and/or store streamflows (Wurbs and Hoffpauir, 2013b). The SB2 Instream Flow Program and SB3 strategy for establishing standard are based on flow regimes that includes four components: subsistence flows, base flows, within-bank high flow pulses, and overbank high pulse flows (Wurbs and Hoffpauir, 2013b). The primary water management practices for satisfying instream flow requirements are to restrict water supply diversions and modify reservoir operations. The SB3 instream flow standards in Texas are assigned priorities based on the dates that the standards are established (Wurbs and Hoffpauir, 2013b). The flow standard or regime refer to the environmental instream flow requirements that are specified to be satisfied or at least to be protected from junior water rights.

A Technical Review Group (TRG) established by the TCEQ provided a compilation of information regarding instream flow assessment tools and several conclusions and recommendations (TCEQ, TPWD, and TWDB, 2008). The methodologies dealt with environmental flow needs of riverine ecosystems are the Lyons method, Consensus Criteria for Environmental Flow Needs (CCEFN), Indicators of Hydrologic Alteration (IHA), Hydrology-based Environmental Flow Regime (HEFS), Texas Hydrologic Assessment Tool (TX-HAT), and the Instream Flow Incremental Methodology (IFIM). The Lyons method and CCEFN provide criteria for determining minimum instream flow limits, the IHA, HEFS, and TX-HAT methods may be used in quantifying instream flow requirement through computing an array of streamflow statistics, and the IFIM is a comprehensive approach using field studies and a set of multiple and analysis tools (Wurbs and Hoffpauir, 2013b).

### 1.4.7 Incorporating Environmental Instream Flows in WAM System

Recent additions to WRAP include capabilities for estimating impacts on water availability for other water users as well as to evaluate capabilities for satisfying environmental instream flow needs (Wurbs and Hoffpauir, 2013b). Environmental instream flow standards can be incorporated in the simulation model using various optional features. Frequency metrics for environmental flow targets and shortages as well as the frequency and characteristics of high pulse flow events can be analyzed using routines in a WRAP post-simulation program.

### 1.4.8 Methods for Evaluating Changes in River Flow Regime

Numerous studies have been investigated for quantifying impacts on stream flow changes by water resources developments based on statistical analyses comparing gauged streamflow data before and after or with and without the developments. Long-term changes in flow characteristics of streamflow data have been evaluated with statistical analysis based on monthly or daily gauged streamflow data, and the index for evaluating flow characteristics are definitely different depending on data time steps.

The Indicators of Hydrologic Alteration (IHA) method was proposed for assessing the degree of hydrologic alteration attributable to human influence (Richter *et al.*, 1996). IHA statistics are grouped into 5 groups that represent flow regime characteristics, and the 5 groups are further classified into 32 hydrologic parameters. Richter *et al.* (1998) suggested the Range of Variability Approach (RVA) method based on natural variability in streamflow characteristics using the IHA method for flow management or restoration. The RVA target can be generally made based on selected percentile levels or a simple multiple of the parameter standard deviations for the natural or pre-development stream flow regime (Richter *et al.*, 1998).

The Dundee Hydrological Regime Alteration Method (DHRAM) was developed to quantify the changes of hydrologic characteristics by water resources development based on the 32 hydrologic parameters of the IHA method (Black *et al.*, 2005). DHRAM can classify the degree of hydrologic alteration into five groups (class 1: un-impacted and class 5: severely impacted condition) using a score (from 0 to 30) yielded by DHRAM based on the overall percentage of changes in the parameters of the IHA method before and after streamflow regulation (Black *et al.*, 2005).

The nondimensional metrics of ecodeficit and ecosurplus based on Flow Duration Curve (FDC) were introduced for evaluating hydrologic alteration in rivers (Vogel *et al.*, 2007). In comparing both FDC of unregulated and regulated flows, the area below the unregulated FDC represents ecodeficit, and conversely, the area above the unregulated FDC represents ecosurplus. Likewise, the metric of ecodeficit is defined as the ratio of the area over the total area under the FDC of unregulated flow, and the metric of ecosurplus is conversely defined as the ratio of the area over the total area (Vogel *et al.*, 2007). Gao *et al.* (2009) developed representative indicators hydrologic alteration based on the nondimensional metrics of ecodeficit and ecosurplus, and proved their availability through principal component analysis of the hydrologic parameters of the IHA method.

Regulation effects on the lower Peace River, Canada were evaluated based on comparing statistical parameters of annual, 1-day, 15-days, and 30-day high indices determined from daily regulated and unregulated flow data (Peters and Prowe, 2001). Changes in hydrologic regime by dams were accessed using the IHA method, and in the research, the serious alterations of hydrologic regime are minimum and maximum flows over different duration (Magilligan and Nislow, 2005). The influence of major dams on hydrology in the Sacramento River Basin, California, USA was evaluated by comparing pre- and post-dams flows with respect to hydrograph characteristics representing frequency, magnitude and shapes based on daily gauged data at 10 gauging stations, located at the downstream of dams (Singer, 2006). Kim *et al.* (2012) assessed flow regulation effects by major dams in the Han River, Korea by comparing FDC of regulated and unregulated flows, generated by the SWAT model.

Lajoie *et al.* (2007) compared monthly flow characteristics including monthly maximum and minimum, inter-annual variability, magnitude and inter-annual variability, frequency, and the coefficients of skewness and kurtosis between natural rivers and regulated rivers based on watershed size, using regression analysis. Impacts of water resources development on flow regimes in the Brazos River, Texas, USA was evaluated based on the monthly flow data of pre- and post-dams (Vogel and Lopes, 2009). In their research, they compared the statistics of annual and monthly data using K-S test.

In the WAM system, frequency metric serves as evaluating capabilities for river system to provide the flow regimes needed for the environment and flow regime alteration by water resources development, and reliability metric is used in evaluating the impact of environmental flow standards on various existing water users (Wurbs and Hoffpauir, 2013b). Trend analysis and flow duration curves are also useful for comparing flow characteristics of naturalized and regulated flows (Wurbs and Hoffpauir, 2013b).

## 1.5 Objectives, Scope and Organization of the Research

The objectives of the research are to:

1. Perform literature review and case study comparative evaluations of methodologies that have been applied in the past or could be applied in the future in accomplishing the following tasks.
    - computing sequences of homogeneous monthly or daily flows from either observed flows or precipitation
    - filling in gaps of missing data
    - updating flow sequences by extending the period covered to near the present
    - synthesizing flows at ungauged sites based on flows at gauged sites
    - disaggregation of monthly flows to daily
2. Develop expanded or improved capabilities for performing the tasks listed above.
3. Perform comparative analyses of flow characteristics that explore key differences between observed, naturalized, and simulated regulated flows that are relevant in modeling reservoir/river system management and especially in establishing environmental flow standards.

The datasets and modeling and analysis tools provided by the WRAP/WAM and SWAT modeling systems are applied in achieving these objectives. Other methods reported in the literature are also explored. The potential for expanding capabilities by adopting watershed precipitation-stream flow modeling is a key focus. The Sabine, Neches, and Guadalupe-San Antonio (GSA) River Basins serve as the primary case studies. Other river basins in Texas are investigated for particular aspects of the research. The research findings are applicable to river/reservoir system modeling in general as well as to the SWAT and WRAP/WAM modeling systems in particular.

The research is designed to support modeling of multiple-purpose reservoir/river system operations in general. However, environmental flow aspects of river basin management and associated modeling are of particular interest.

Chapter II describes the methodologies adopted for this research. Section 2.1 focuses on a method for infilling missing naturalized flows using the combination of the SWAT model and a transfer method. Section 2.2 describes a new approach to obtain the parameters for the drainage area ratio method and a method to remove transfer biases on the regional statistic. The methodology for disaggregation of monthly to daily naturalized flow sequences is described in Section 2.3. The section includes the strategies for the SWAT model calibrations and flow pattern evaluations. Section 2.4 introduces a strategy to evaluate environmental flow standards based on the simulation outputs of the daily WRAP model.

The WAM datasets for the Sabine, Neches, and GSA River Basins serve as the case studies for this research. Chapter III contains the basin descriptions and WAM datasets for the basins. The primary WAM water use scenario employed for this research is the full authorized use scenario.

Chapter IV introduces a proposed method for infilling missing naturalized flows. This chapter is organized into sections that describe a procedure, data used, the calibration strategy of the SWAT model, and MOVE2 method, respectively. Section 4.5 shows how much the method improves the results through comparative analyses.

Chapter V focuses on developing naturalized flows at ungauged sites based on flows at gauged sites. The procedures to optimize the correction factor and exponent for the drainage area ratio method are introduced. A new approach is proved through the comparative analyses in section 5.2. Section 5.3 demonstrates how to remove transfer biases in the regional statistical method through the case studies.

Chapter VI presents a new method to generate simultaneously daily flow patterns at multiple sites using the SWAT model. This chapter contains the watershed delineation methods, model calibration strategies with the monthly or daily flow datasets, and comparative evaluation of disaggregated daily flows. The selected disaggregated flow datasets are finally used as input data for deriving routing parameters and daily streamflow patterns for the simulation studies in Chapter VII.

Chapter VII is organized into sections that individually focus on SB3 environmental flow standards for each WAM, environmental flow standards modeling strategies, their target at the control points based on the simulation results.

Chapter VIII investigates sequences of daily observed flows during historical periods prior to significant water resources development versus during more recent periods reflecting development and naturalized versus regulated flows from the daily WAMs at USGS gauging stations for Sabine, Neches, and Guadalupe and San Antonio River Basins.

Chapter IX focuses on evaluating environmental flow standards through the simulation studies using the daily WRAP model. Three case studies are performed with emphasis on hydrological regime alteration on river flows due to human influences and evaluation of their roles and influences on river flows.

The summary and conclusion of the research are presented in Chapter X. The methods and strategies developed by this research with respect to the effectiveness in addressing the key issues described in this Section are firstly summarized. The findings of the case studies through evaluating environmental flow standards are also summarized to provide feedback and guidance for modifying the existing environmental flow standards in the basins or establishing the new standards in other basins.

# CHAPTER II
# RESEARCH METHODOLOGY

This research includes the following component tasks corresponding to the research objectives discussed in the preceding Chapter I:

- developing a method for synthesizing missing monthly naturalized flows data using the SWAT model, including both filling in gaps in missing data and updating or extending sequences to the present
- suggesting a method to remove the bias on the drainage area ratio in transferring monthly naturalized flow sequences to ungauged sites based on flows at gauged sites
- developing a strategy for developing daily flow patterns simultaneously at multiple sites using the SWAT model that preserves monthly naturalized flow volumes while modeling temporal and spatial characteristics of daily natural flows
- exploring strategies for quantifying the effects of development on stream flow that are useful in studies of environmental instream flow requirements
- evaluating the effect on regulated and unappropriated flows in the case study river basins of the environmental flow standards recently established by the TCEQ through the Senate Bill 3 (SB3) process.

The Sabine, Neches, and Guadalupe-San Antonio (GSA) River Basins serve as the primary case studies, but the Trinity River Basin is also adopted to various extents in certain parts of the research. The Neches and Sabine River Basins represent conditions of high rainfall, forested watersheds, minimal surface/groundwater interactions, and relatively low population density. The GSA River Basin is characterized by lower rainfall, major surface/groundwater interactions, and much higher population densities.

## 2.1 A Proposed Method for Infilling Missing Naturalized Flows Using the SWAT Model

A method is developed in this research for filling in missing naturalized flows using the SWAT model. The method is applicable both to filling in periods of missing data associated with gaps in historical gauge records and to updating the hydrologic simulation period covered by the WAM datasets to the present. The process for filling in missing data consists of three steps. The first step is to adjust partially recorded data to naturalized data by removing human impacts. The second step is to develop a SWAT model to synthesize naturalized streamflow data after calibration with the available naturalized flow for the partial period. The third step is to fill in gaps in the missing data using a linear transfer method with the streamflow data for the full period generated with the SWAT model.

### 2.1.1 Transfer method

The models that can consider heterogeneous relationships between base and target stations are not necessary because the monthly streamflow sequence generated by the SWAT model is homogeneous, and the partially recorded streamflow data are also adjusted by removing human imparts prior to the application of this procedure. Thus, linear models can be utilized as a transfer method. While the regression can provide the best estimate (minimum square error) for each individual value, it cannot preserve any particular statistical characteristics of the record data (Hirsch 1982). Thus, Hirsch (1982) suggested that maintenance of variance extension, type 2 method (MOVE2) is the most effective of four linear methods in terms of infilling missing data in preserving the statistical properties of the recorded data they are intended to represent. The MOVE2 method is

$$\hat{y}(i) = \widehat{m}(y) + \frac{\hat{S}(y)}{S(x)}[x(i) - m(x)] \tag{2.1}$$

In order to estimate the unbiased sample mean and standard deviation, the parameters $\widehat{m}(y)$ and $\hat{S}(y)$ developed by Matalas and Jacobs (1964) were used as

$$\widehat{m}(y) = m(y_1) + \frac{N_1}{(N_1+N_2)} r \frac{S(y_1)}{S(x_2)}(m(x_2) - m(x_1)) \tag{2.2}$$

$$\hat{S}^2(y) = \frac{1}{N_1+N_2-1}\Big\{(N_1-1)S^2(y_1) + (N_2-1)r^2\frac{S^2(y_1)}{S^2(x_1)}S^2(x_2) + (N_2-1)\alpha^2(1-r^2)S^2(y_1) + \frac{N_1N_2}{(N_1+N_2)}r^2\frac{S^2(y_1)}{S^2(x_1)}(m(x_2)-m(x_1))^2\Big\} \quad (2.3)$$

$$\alpha^2 = \frac{N_2(N_1-4)(N_1-1)}{(N_2-1)(N_1-3)(N_1-2)} \quad (2.4)$$

Where,

$i$ is an index of time,

$m(x)$ is the sample mean of recorded data at the base station

$m(y_1)$ is the sample mean of recorded data at the target station

$x_1$ is the flow values for recorded period of the target station at the base station,

$y_1$ is the flow values for recorded period at the target station,

$x_2$ is the flow values for target period at the base station,

$N_1$ is the number of recorded period of the target station,

$N_2$ is the number of target period at the target station,

$m(x_1)$ is the sample mean of recorded data of the target station at the base station,

$m(x_2)$ is the sample mean of recorded data for the target period at the base station,

$S(y_1)$ is the sample deviation of recorded data at the target station,

$S(x_2)$ is the sample deviation of recorded data for target period at the base station,

r is product moment correlation coefficient between the recorded data at the base and target stations.

2.1.2 Monthly SWAT Model

The SWAT model can perform well in predicting monthly streamflow rates (Gassman, 2007), and this has been successfully proved in the literature (Gassman, 2007 and 2014 and Douglas-Mankin *et al.*, 2010). Thus, the SWAT model can produce the monthly streamflow sequence that is strongly correlated with the streamflow sequence at a target station if there is partially recorded streamflow sequence at the station. Parameter calibration is a key process to enhance the accuracy of the SWAT model in most applications if accurate known streamflow data are available for calibration. The calibrated parameters for the three case study river basins are selected based on expert judgement and on the recommendations from related literature as listed in Table 2.1.

The parameters are calibrated with monthly naturalized flow data, generated based on recorded data. The SWAT-CUP (2012 version), semi-automated calibration model is used for calibration with the sequential uncertainty fitting algorithm (Abbaspour *et al.*, 2004), and the coefficient of determination ($R^2$) is used as the objective function to get the most linear correlated synthesized flow sequences with naturalized flow data.

Table 2.1 Calibrated Parameters for SWAT Models

| Classification | Parameters |
|---|---|
| Effective Rainfall | CN |
| Ground Water | Alpha_BF |
| | GW_Delay |
| | GWqmn |
| | Revapmn |
| | GW_Revap |
| | RCHARG_DP |
| Soil Water Content | Sol_AWC |
| | Sol_K |
| Evaportranspiration | ESCO |
| | EPCO |
| Routing | Surlag (surface, HRU) |
| | CH_N2 (Channel, subbasin) |
| Channel Loss | CH_K2 |

## 2.2 Refinement of Methods for Developing Naturalized Monthly Flows at Ungauged Sites Based on Flows at Gauged Sites

### 2.2.1 Drainage Area Ratio Method

The drainage-area ratio method with or without considering channel losses commonly is used to develop naturalized monthly flow sequences at secondary control points based on naturalized monthly flow datasets at primary control points in the WRAP/WAM model as follows (Wurbs, 2006):

$$Q_{ungauged} = R_{DA} Q_{gauged} \tag{2.5}$$

$$R_{DA} = \frac{DA_{ungauged}}{DA_{gauged}} \tag{2.6}$$

Equation (2.5) may optionally be changed to Equation (2.7 or 2.8) in situations where the ungauged site is located upstream of the gauged sites with channel losses occurring between the sites at rates that are significantly greater than the loss rates in the watershed above the ungauged sites (Wurbs, 2006).

$$Q_{ungauged} = R_{DA}(Q_{gauged} + F_{CL} Q_{ungauged}) \tag{2.7}$$

or

$$Q_{ungauged} = Q_{gauged} \left(\frac{R_{DA}}{1 - R_{DA} F_{CL}}\right) \tag{2.8}$$

Emerson *et al.* (2005) suggested the following general equation in order to improve the accuracy of the DAR method:

$$Q_y = Q_x K \left(\frac{A_y}{A_x}\right)^{\emptyset} \tag{2.9}$$

Where $Q_y$ is streamflow at ungauged site, $Q_x$ is streamflow at gauged site, $K$ is Bias correction factor, $A_y/A_x$ is drainage area ratio (ungauged to gauged), and $\emptyset$ is exponent.

The estimation of bias correction factor and exponent is based here on calibrating the two parameters using a simple optimization method with the General Reduced Gradient Algorithm (GRG) in Microsoft Excel. The DAR method is also one of linear equations, and this can be simply represented as:

$$Y = BX \tag{2.10}$$

Assuming $Y$ is $Q_y$, and $X$ is $Q_x$. B can be written as:

$$B = K \left(\frac{A_y}{A_x}\right)^{\emptyset} \tag{2.11}$$

Bs can be estimated by linear regression equation without intercepts, made from selected primary control point pairs with high correlate coefficient (more than r=0.91). Both drainage areas are known values, so unknown values ($K$ and $\emptyset$) can be calibrated using an optimization method. The automated calibration method needs an objection function for determining optimality of alternative sets of values for the decision variables ($K$ and $\emptyset$). The optimization process is to find values of decision variable that minimize a specific objective function (OF) defined by Equation (2.12).

$$\mathrm{OF} = \frac{1}{n}\sum\left(\frac{(B-B_e)}{B}\right)^2 \qquad (2.12)$$

Where, $B$ is a slope value from datasets, and $B_e$ is calculated with Equation (2.11).

### 2.2.2 Regional Statistical Method

Hirsch (1979) suggested a regional statistical method, and showed the method has apparently better performance than the DAR, but Farmer and Vogel (2013) revealed that the regional statistical method may not always be superior to the DAR method in their research. The equation of the method is

$$Q_y = \mu_y + \frac{\sigma_y}{\sigma_x}(Q_x - \mu_x) \qquad (2.13)$$

Where, $Q_y$ is streamflow at ungauged site, $Q_x$ is streamflow at gauged site, $\sigma_y$ is standard deviation estimated regional regression, $\sigma_x$ is standard deviation from gauged data, $\mu_y$ is mean estimated regional regression, and $\mu_x$ is mean from gauged data.

The regression equations used to determine $\mu_y$ and $\sigma_y$ are based on the various hydrological features in the basin (Hirsh, 1979). Emerson *et al.* (2005) showed that average season flows at ungauged sites can be estimated by the regression equation, made by linear relationship between drainage area and average seasonal flows at gauged sites. Likewise, if mean and standard deviation for an ungauged site are estimated by a regional equation based on only drainage area, the regional statistics method may be used in developing flow sequences at ungauged based on flows at gauged sites under the same condition of the DAR method. In this proposed research, the reason why the regional statistical method may not synthesize flow sequences better than the DAR method will be explained, and a new approach to minimize bias on the method will be suggested.

The sample standard deviation from data may have bias as:

$$log\sigma_x = logS_x + E(\varepsilon_1) \qquad (2.14)$$

Where, $\sigma_x$ is population standard deviation, $S_x$ is the sample standard deviation, and $E(\varepsilon_1)$ is the expected bias. Similarly, the estimated standard deviation by regional regression may also have bias as:

$$log\sigma_y = logS_y + E(\varepsilon_2) \quad (2.15)$$

Where, $\sigma_y$ is population standard deviation, $S_y$ is estimated standard deviation, and $E(\varepsilon_2)$ is expected bias. Equation (2.14) and Equation (2.15) can be transformed respectively to:

$$\sigma_x = S_x \, 10^{E(\varepsilon_1)} \quad (2.16)$$

$$\sigma_y = S_y \, 10^{E(\varepsilon_2)} \quad (2.17)$$

When Equations (2.14 and 2.15) are substituted into Equation (2.13), biases of both standard deviations will be retained in a different form like $10^{E(\varepsilon_2)}/\ 10^{E(\varepsilon_1)}$ in Equation (2.13). For this reason, the regional statistical method may result in poor performance compared with the DAR method. If both standard deviations from a same source are used, bias can be removed like $10^{E(\varepsilon_1)}/\ 10^{E(\varepsilon_1)}$ =1. Thus, if both statistic moments from regional regression equation are used, the regional statistical method will be an alternative of the DAR method.

## 2.3 Disaggregation of Monthly to Daily Naturalized Flow Sequences Using the SWAT Model

Multiple daily flow patterns should be necessary for disaggregation of monthly to daily naturalized flow datasets keeping their spatial consistency among all sites within a river basin. In other words, a daily flow pattern at a site should not only cover a period of monthly flow data but also contain natural flow characteristics without any human influences and spatial consistency such as routing effects between up and downstream sites within a river basin.

The daily SWAT model can be a useful solution to simultaneously generating daily flow patterns at all primary control points of a basin in WAM datasets, if there are reliable daily rainfall data, well-spatially distributed within a river basin. The National Climatic Data Center (NCDC) provides daily precipitation data nationwide, even though gaps of missing data may occur, and the SWAT model can generate other climate data.

### 2.3.1 Calibration Strategies

Parameter calibration is an important aspect of developing an appropriate daily SWAT model for synthesizing daily flow patterns. There are two possible strategies for calibrating the SWAT model. The first strategy is to calibrate the model with monthly naturalized flows at primary control points, and then the daily flow sequences at all sites of interest in the basin are generated using the calibrated model. The second approach is to calibrate the model with daily recorded data that can be considered as naturalized flow sequence for at least five years, and to validate the model with daily recorded data that can also be regarded as naturalized flows for at least five years at sites. The daily flow sequences at all sites of interest in the basin are synthesized using the calibrated and validated model.

The first strategy requires enough long period recorded data, and implementation of multiple-site calibration for considering the spatial consistency of the model. However, the calibrated model with monthly recorded data may not guarantee performance of the daily model. The second strategy should be the best solution in generating homogeneous daily flow sequence at pertinent sites in the basin, but it is very restricted by limited available recorded data at the sites of interest. It is actually impossible to get perfect daily naturalized flow records. In reality, if there are long period-of-record data, the data sequence prior to evident human influence such as initial dam impoundment can be considered naturalized flow sequence, and then used for the model calibration after dividing the data into pre- and post-human influence. Multiple-site calibration may be impossible because generally only a limited number of sites have available records.

Accordingly, the more appropriate strategy for the daily model calibration will be achieved through comparative evaluation of the two daily flow sequences, developed by the alternative strategies mentioned above because each basin has different hydrologic conditions and recorded data.

### 2.3.2 Comparative Evaluation

Recorded daily naturalized flow data are needed for comparative evaluation of disaggregated flow sequences by synthesized daily flow patterns. In reality, it may be impossible to get perfectly homogeneous recorded data. However, if there are recorded flow sequences at a site for a period before a dam impoundment, these may be considered daily flow data that are not exact but similar to naturalized flows without human influences because it is well-known that a dam impoundation has seriously changed flow regime in a river.

Disaggregated daily sequences from monthly should have highly linear correlation, similar flow characteristics, and overall hydrologic states (drought and flood years) with recorded daily data for a specific period at same sites. Four different methods are adopted for achieving these evaluation conditions as listed in Table 2.2.

Table 2.2 Four Different Evaluating Methods

| Methods | Purpose | Quantification method |
|---|---|---|
| Nash-Sutcliff Coefficient ($-\infty$ to 1) | Streamflow timing (higher is better) | - Comparing USGS vs. Monthly base disaggregated with USGS vs. Daily based disaggregated<br>- Total score of each method in a basin<br>- Better is 2, similar is 1, and worse is 0 |
| Flow Frequency Metric | Streamflow regime (Qualitative Evaluation) | |
| DHRAM (IHA) (0 to 30 points) | Hydrologic characteristics alteration (Lower is better) | |
| Median Annual Flow Duration Curve | Overall hydrologic state of a river (Drought and Flood years ) (Qualitative Evaluation) | |

All scores from each method are summed up to select the more appropriate calibration strategy based on the total scoring method adopted in this research. The total scoring method is shown in Table 2.3.

Table 2.3 Total Scoring Method

| Methods | Score (0 to 8) | Selection |
|---|---|---|
| Nash-Sutcliff Coefficient | High score is 2<br>Same score is 1<br>Low score is 0 | The calibration method with the highest total score is finally selected for disaggregation of monthly to daily flow sequences |
| Flow Frequency Metric | High score is 2<br>Same score is 1<br>Low score is 0 | |
| DHRAM (IHA) | High score is 2<br>Same score is 1<br>Low score is 0 | |
| Median Annual Flow Duration Curve | High score is 2<br>Same score is 1<br>Low score is 0 | |

## 2.4 Analyses of Environmental Flow Standards

Research and development to expand WRAP/WAM capabilities performed at Texas A&M University sponsored by the TCEQ over the past several years have focused on converting monthly WAM models to daily and incorporating SB3 environmental flow standards for six case study river basins: Brazos, Colorado, Trinity, Guadalupe-San Antonio, Neches, and Sabine. The SB3 environmental flow standards are defined in terms of four flow regimes: subsistence flows, base flows, within-bank pulse flows, and overbank pulse flows (Wurbs and Hoffpauir, 2013b; Pauls 2014). Pauls (2014) developed metrics for evaluating achievement of the environmental flow standards focusing on whether river flows meet to the environmental flow standards with variations in the flow standards or water right priorities and impacts on existing water rights.

As discussed Chapter I, the Indicators of Hydrologic Alteration (IHA) method (Richter *et al.* 1996) for assessing the degree of hydrologic alteration attributable to human influence has been applied throughout the world. The IHA methodology is based on computing values for groups of statistical parameters for the components of a flow regime. Annual median flow duration curves provide a graphical illustration of the overall hydrologic states of a river (Vogel *et al.*, 2007). A flow duration curve (FDC) can be easily made by the relationship between ordered median daily streamflow records and a function of their exceedance probability representing the exceedance probability of daily flows in a median year (Vogel *et al.*, 2007).

The research reported in this dissertation further investigates statistical parameters that can be used to quantify long-term flow changes and the extent to which environmental flow changes can be achieved subject to water availability using the two different assessment methods mentioned above. The WRAP model and these methods are applied to develop an enhanced understanding of river flows in the GSA, Neches, and Sabine case study river basins.

# CHAPTER III
# CASE STUDY BASINS

The SWAT and WRAP/WAM modeling systems are applied in the dissertation research to the Guadalupe and San Antonio (GSA), Neches, and Sabine River Basins. Available flow data from other river basins are also included in some of the analyses performed in the research.

## 3.1 Sabin River Basin

### 3.1.1 Description of the Basin

The Sabine River Basin is located in east of Texas encompassing a part of Texas and a part of Louisiana as shown in Figure 3.1. The Sabine River Basin is about 300 miles long and has a maximum width of 48 miles. Its total drainage area is about 9,760 square miles, with 7,400 square miles (76 percent) in Texas and the remainder in Louisiana. The drainage area of the upper basin at the point near the town of Logansport, Louisiana, where the river becomes the state boundary, is 4,850 square miles. The Sabine River along with Toledo Bend Reservoir serves as a 265 miles segment of the state border. Major tributaries include Cow Bayou, Bayou Anacoco, Bayou Toro, Tenaha Creek, Martin Creek, Murvaul Bayou, Big Sandy Creek, and Lake Fork Creek. The Sabine River flows into Sabine Lake which is a 14-mile long, 90,000-acre estuary formed by the confluence of the Sabine and Sabine Rivers. Sabine Pass is the natural outlet of Sabine Lake into the Gulf of Mexico. The largest city in the river basin is Longview with a population of 80,500 located in the upper basin (Wurbs *et al.*, 2014a). Mean annual rainfall ranges from 44 inches in the upper basin to 56 inches near the Gulf of Mexico.

### 3.1.2 Sabine WAM

TCEQ contractors developed the original Sabine WAM as documented by a 2001 report entitled *Water Availability Modeling for the Sabine River Basin – Final Report*. The

TCEQ has periodically updated the Sabine WAM water rights data files along with the WAMs for the other river basins of the state. The authorized use scenario Sabine WAM dataset with latest TCEQ revisions dated August 8, 2007 was used for developing the daily WAM. The Sabine WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots sabine3 and sabine8, respectively. *WRAP-SIM* prints a listing to its message file of the number of various system components. The *SIM* counts in Table 3.1 are from the August 2007 Sabine WAM full authorization and current conditions scenarios (Wurbs *et al.*, 2014a).

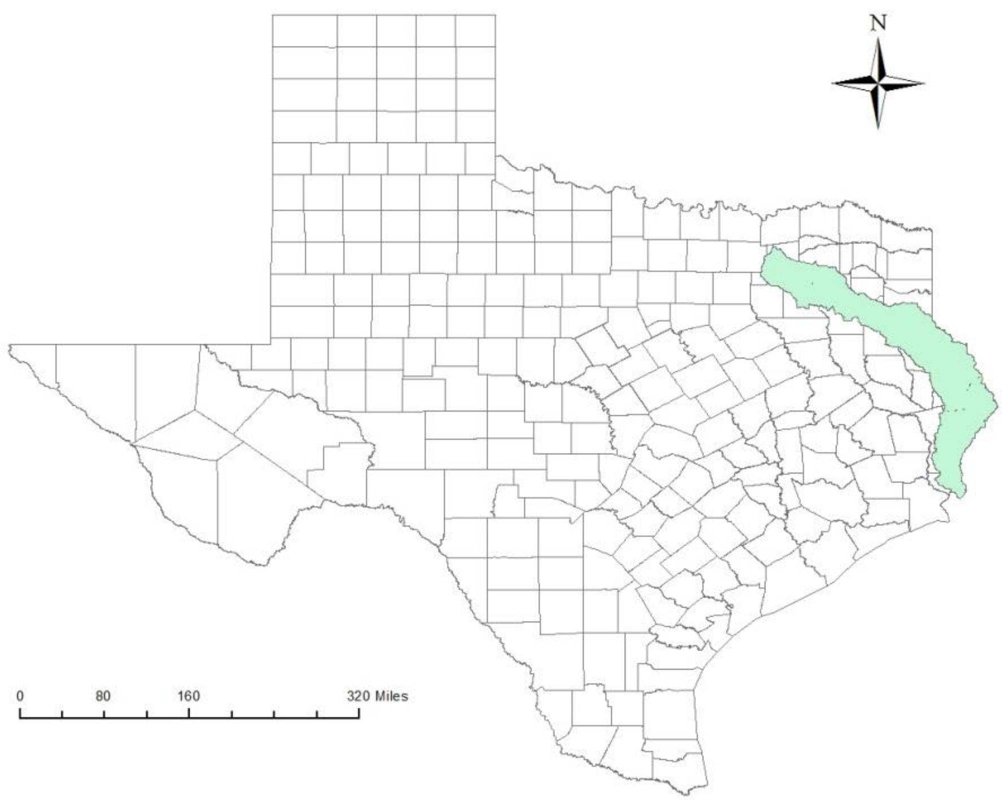



Figure 3.1 Location of Sabine River Basin

Table 3.1 Number of System Components in Sabine WAM Datasets

| Latest Update of Datasets<br>Water Use Scenario<br>Filename | Aug 2007<br>Authorized<br>sabine3 | Aug 2007<br>Current<br>sabine8 |
|---|---|---|
| total number of control points | 387 | 387 |
| number of primary control points | 27 | 27 |
| control points with evaporation-precip rates | 20 | 20 |
| number of reservoirs as counted by *SIM* | 212 | 213 |
| number of *WR* record water rights | 321 | 328 |
| number of instream flow *IF* record rights | 22 | 23 |
| number of system water rights | 18 | 18 |
| number of hydropower rights | 1 | 1 |
| number of dual simulation rights | 4 | 4 |
| number of *FD* records in DIS file | 358 | 358 |

*Control points*

Primary control points have monthly naturalized flow data on *IN* records in a FLO file in a *SIM* input dataset. However, the *SIM* simulation calculates naturalized flows at all other control points, called *secondary* control points based on the naturalized flows provided at the primary control points and watershed parameters (Wurbs *et al.*, 2014a).

There are 27 primary control points and 360 secondary control points in the Sabine WAM. Table 3.2 lists twenty-one of the control points. The 27 primary control points contain 17 USGS gauging stations listed in Table 3.2, the basin outlet (SRSL) also included in Table 3.2, but Table 3.2 does not list 8 control points used for referencing *EV* record reservoir evaporation rates, and another control point (CYPRES) also omitted from the table. Control point CYPRES is an accounting reservoir used in modeling the refilling of Brandy Branch Reservoir from an inter basin transfer. Only the 18 conventional primary control points serves as primary control points. The locations of the 18 primary control points are shown in Figures 3.2 and 3.3.

Table 3.2 Primary Control Points in the Sabine WAM

| Control Point | Location | Gage Number | Area (mile$^2$) | Period of Record |
|---|---|---|---|---|
| CFGV | Cowleech Fork Sabine at Greenville | 8017200 | 77.7 | 03/59 to present |
| SRWP | Sabine River near Wills Point, TX | 8017410 | 756 | 10/70 to present |
| SRMN | Sabine River near Mineola, TX | 8018500 | 1,357 | 5/39–9/59, 10/67 to present |
| LFQT | Lake Fork Creek near Quitman, TX | 8019000 | 585 | 7/24-4/26, 3/39 to present |
| BSBS | Big Sandy Creek near Big Sandy, TX | 8019500 | 231 | 02/39 to present |
| SRGW | Sabine River near Gladewater, TX | 8020000 | 2,791 | 10/32 to present |
| SRBE | Sabine River near Beckville, TX | 8022040 | 3,589 | 10/38 to present |
| MCTT | Martin Creek near Tatum, TX | 8022070 | 148 | 4/74 to 1996 |
| MBGR | Murvaul Bayou near Gary, TX | 8022300 | 134 | 58-83 |
| SRLP | Sabine River at Logansport, LA | 8022500 | 4,842 | 7/03-2/68 (Q), 3/68-pres (stage) |
| TCSV | Tenaha Creek near Shelbyville, TX | 8023200 | 97.8 | 03/52-06/81 |
| BTTR | Bayou Toro near Toro, LA | 8025500 | 148 | 10/55-09/86, 10/88-present |
| SRBU | Sabine River near Burkeville, TX | 8026000 | 7,482 | 9/55 to present |
| BARP | Bayou Anacoco near Rosepine, LA | 8028000 | 365 | 10/51-10/99 |
| SRBW | Sabine River near Bon Wier, TX | 8028500 | 8,229 | 10/23 to present |
| SRRL | Sabine River near Ruliff, TX | 8030500 | 9,329 | 10/24 to present |
| CBMV | Cow Bayou near Mauriceville, TX | 8031000 | 83.3 | 04/52-09/86 |
| SRSL | Sabine River at Sabine Lake | | 9,756 | |

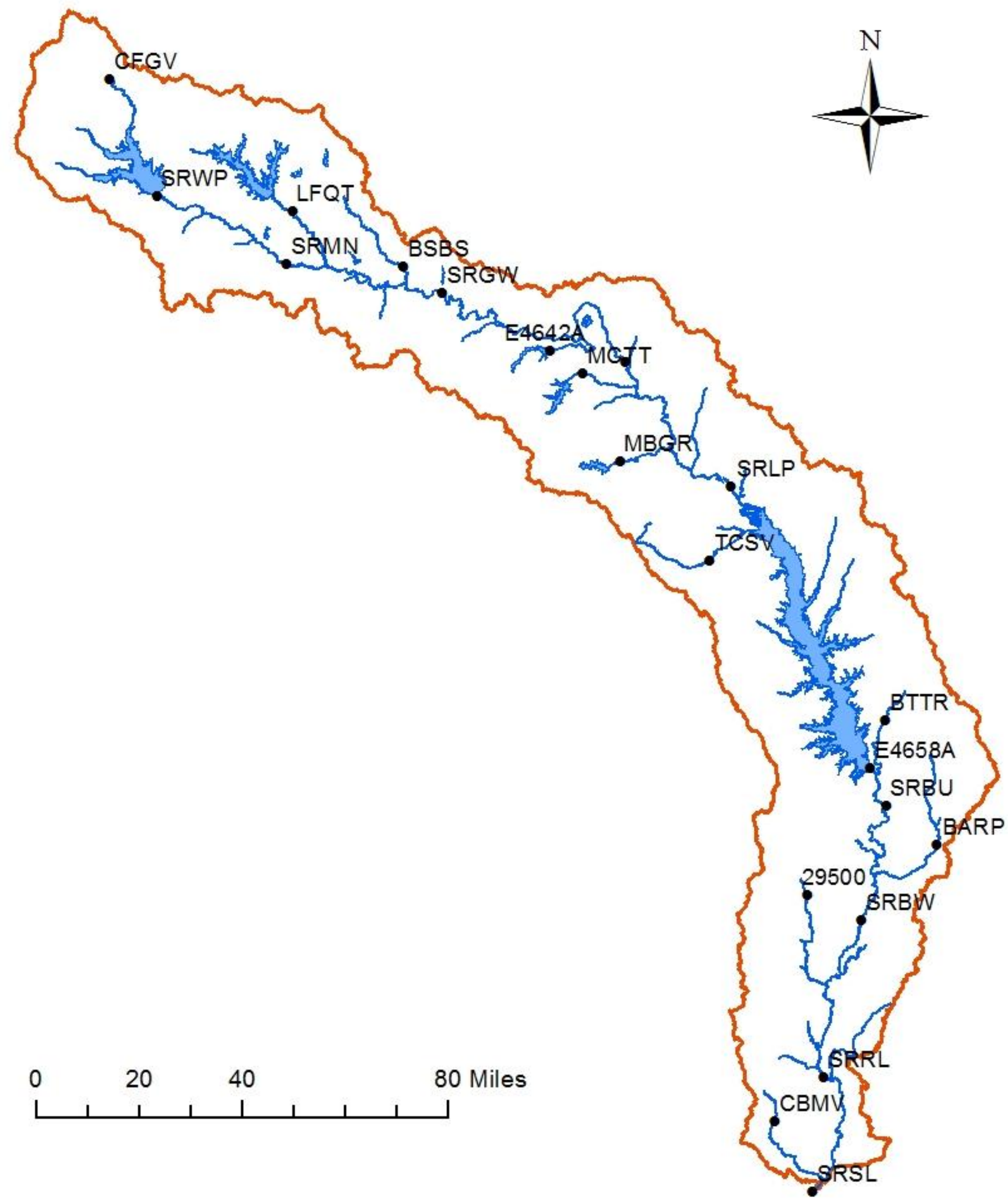



Figure 3.2 Map of Control Points in the Sabine WAM

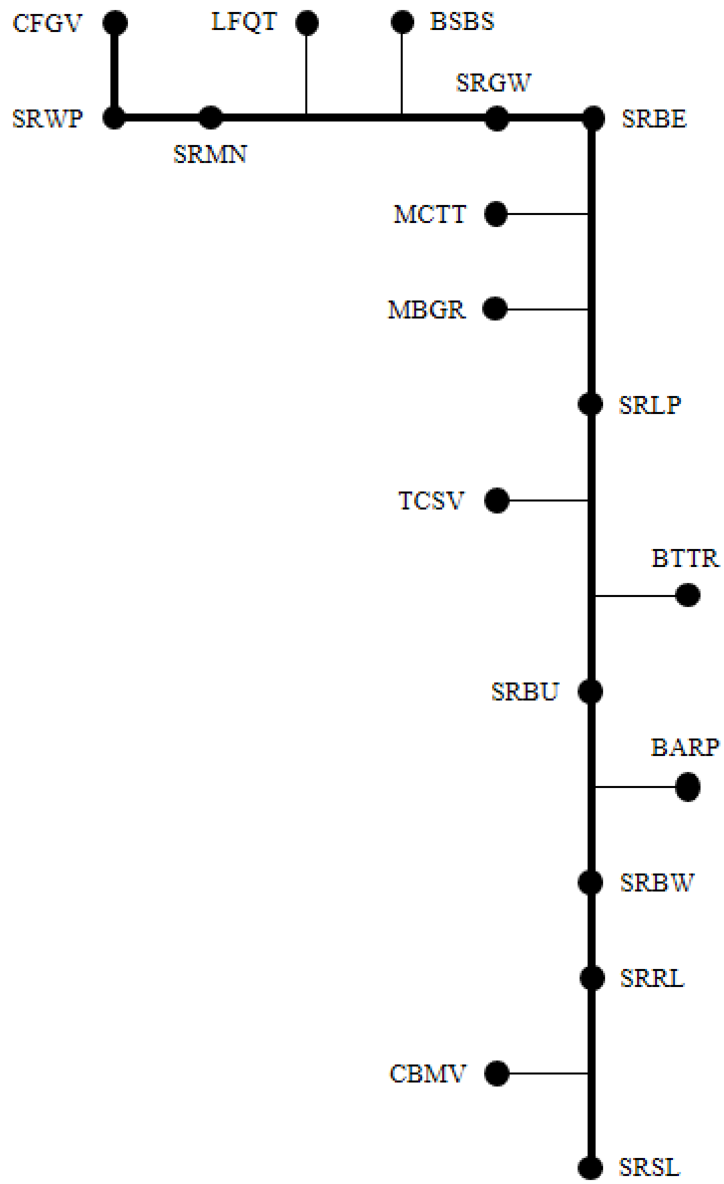



Figure 3.3 Schematic of Primary Control Points (Wurbs *et al.*, 2014a)

*Reservoirs*

There are 212 reservoirs in the authorized use (run 3) and 213 reservoirs in the current use (run 8) datasets last updated in August 2007. Table 3.3 lists the 13 major reservoirs with storage capacities of 5,000 acre-feet or greater located in Texas with their storage capacities from the authorized use scenario DAT file. The total permitted conservation storage capacity of 6,343,780 acre-feet of the 13 major reservoirs capture 99.1 percent of the total storage capacity of 6,403,210 acre-feet in the 212 reservoirs. The last column of Table 3.3 accounts for the map identifiers and refers to Figure 3.4.

Table 3.3 Major Reservoirs in the Sabine WAM

| Reservoir | Stream | Drainage Area | Initial Impoundment | Conservation Storage | Reservoir ID | Control Point | Map ID |
|---|---|---|---|---|---|---|---|
| | | (sq miles) | | (acre-feet) | | | |
| Toledo Bend | Sabine River | 7,178 | Oct 1966 | 4,477,000 | TOLEDO | E4658A | 1 |
| Lake Tawakoni | Sabine River | 756 | Oct 1960 | 927,440 | TAWAKO | E4670A | 2 |
| Lake Fork | Lake Fork Creek | 493 | July 1979 | 675,819 | FORK | E4669A | 3 |
| Martin Lake | Martin Creek | 130 | April 1974 | 77,619 | MARTIN | E4649A | 4 |
| Lake Cherokee | Cherokee Bayou | 158 | Oct 1948 | 62,400 | CHEROK | E4642A | 5 |
| Lake Murvaul | Murvaul Bayou | 115 | Dec 1957 | 44,650 | MURVAU | E4654A | 6 |
| Brandy Branch | Brandy Branch | 4 | 1982 | 29,513 | BRANDY | E4647A | 7 |
| Hawkins | Little Sandy | 30 | Aug 1962 | 11,890 | HAWKIN | E4736A | 8 |
| Winnsboro | Big Sandy | 27 | June 1962 | 8,100 | WINNSB | E4749A | 9 |
| Holbrook | Keys Creek | 15 | Sept 1962 | 7,990 | HOLBRK | E4690A | 10 |
| Quitman | Dry Creek | 31 | May 1962 | 7,440 | QUITMA | E4708A | 11 |
| Lake Gladewater | Glade Creek | 35 | Sept 1952 | 6,950 | GLADE | E4762A | 13 |
| Greenville City Lakes | Cowleech Fork of Sabine River | Minimal (off-channel) | 1888-1957 | 6,969 | R4665A | E4665A | 12 |

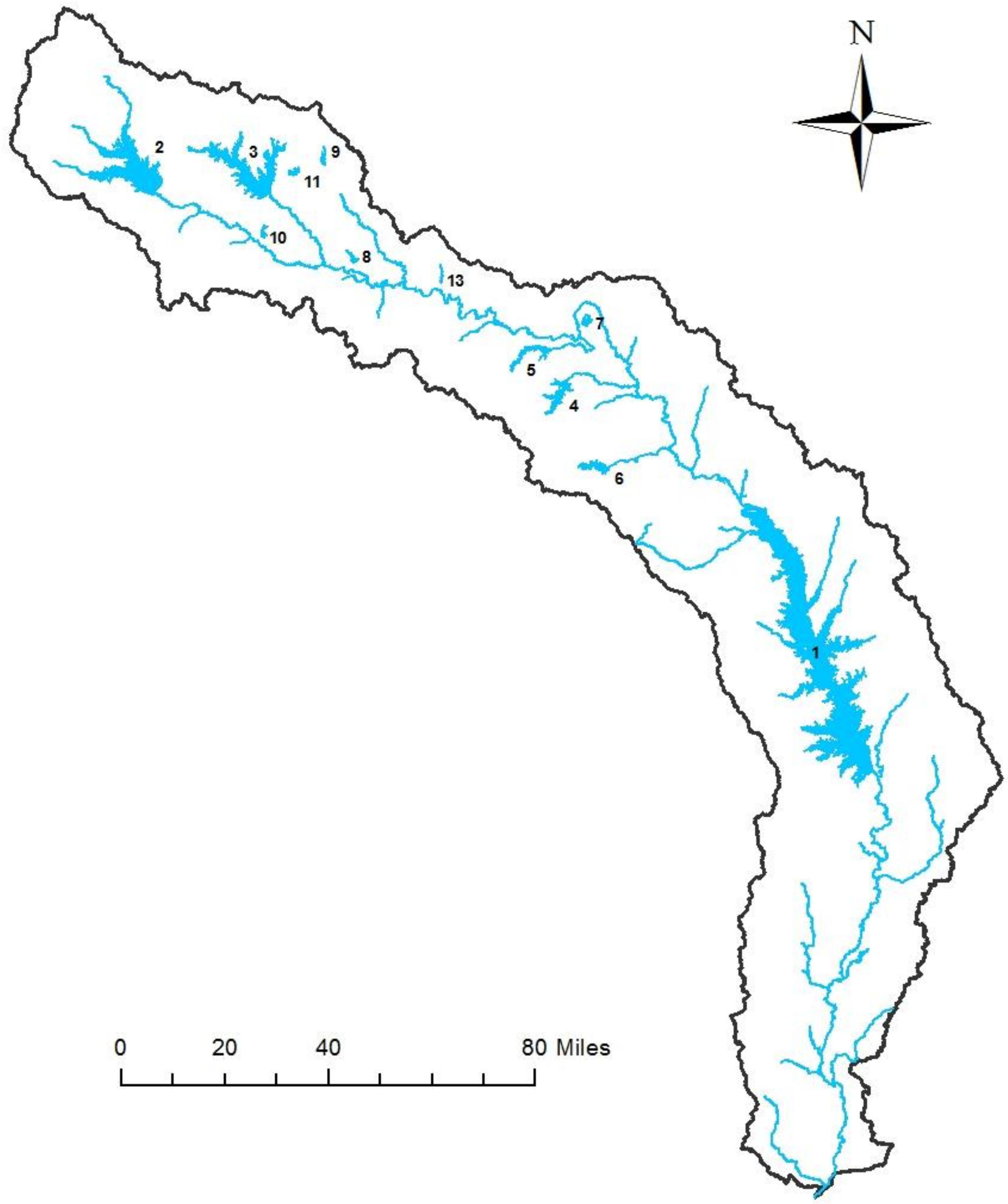



Figure 3.4 Major Reservoirs in the Sabine River Basin

*Water rights*

Table 3.4 summarizes the diversion data included in the 183 water rights in the Texas water right permit system, which excludes the water allocated to Louisiana under the Sabine River Basin Interstate Compact between Texas and Louisiana (Wurbs *et al.*, 2014a). Table 3.4 summarizes diversion rights with the diversions being categorized by location upstream or downstream of Stateline. Stateline serves as the border between Texas and Louisiana is located just upstream of Toledo Bend Reservoir. This is 265 mile far from the upstream end of the Sabine River.

Table 3.4 Texas Water Rights Diversion Summary from 2001 Sabine WAM Report

| | Diversion Rights Totals in acre-feet/year | | | | | |
|---|---|---|---|---|---|---|
| | Municipal | Industrial | Recreation | Mining | Irrigation | Total |
| Upstream of Stateline | 522,672 | 190,664 | 10 | 701 | 6,465 | 720,512 |
| Downstream of Stateline | 101,460 | 967,635 | 0 | 0 | 96,817 | 1,165,912 |
| Total | 624,132 | 1,158,299 | 10 | 701 | 103,282 | 1,886,424 |

There are 321 *WR* records and 22 *IF* records that model water allocated to Louisiana as well as Texas water right permits in the Sabine WAM authorized use scenario (run 3) DAT file and 328 *WR* records and 23 *IF* records in the current use scenario (run 8) DAT file. Most of the 387 control points have water rights. However, 53 *WR* records at the 19 control points listed in Table 3.5 with a total permitted diversion of 2,493,451 acre-feet/year capture 99.5 percent of the total permitted diversion of 2,505,650 acre-feet/year specified in the 321 *WR* records.

Table 3.5 Summary of Water Rights in Authorized Use Scenario Sabine WAM

| Control Point | Number Rights | Permitted Diversions (ac-ft/yr) | Number Reservoirs | Storage Capacity (acre-feet) | Priorities Range From | To |
|---|---|---|---|---|---|---|
| USRBU | 7 | 997,785 | 0 | 0 | 30001231 | 30001231 |
| E4658A | 3 | 502,215 | 1 | 4477000 | 30001231 | 30001231 |
| E4670A | 2 | 238,100 | 1 | 927440 | 19550912 | 19850813 |
| E4669A | 2 | 188,660 | 1 | 675819 | 19740626 | 19850813 |
| E4662A | 9 | 147,100 | 0 | 0 | 19260224 | 19781113 |
| E4631A | 1 | 134,500 | 0 | 0 | 19490919 | 19490919 |
| 4631G | 1 | 112,000 | 0 | 0 | 19750428 | 19750428 |
| E4642A | 5 | 62,400 | 1 | 62400 | 19461005 | 19461005 |
| E4649A | 1 | 25,000 | 1 | 77619 | 19710719 | 19710719 |
| E4631C | 2 | 22,500 | 1 | 4900 | 19570107 | 19570107 |
| E4654A | 2 | 22,400 | 1 | 44650 | 19560719 | 19560719 |
| E5090P | 1 | 13,860 | 0 | 0 | 19860826 | 19860826 |
| E4647A | 2 | 11,000 | 1 | 29513 | 19780821 | 19780821 |
| E4759B | 5 | 5,600 | 1 | 183 | 19350424 | 19450713 |
| E4665A | 3 | 4,159 | 1 | 6969 | 19250630 | 19910925 |
| E4762A | 2 | 2,125 | 1 | 6950 | 19510517 | 20000808 |
| E4675B | 1 | 1,500 | 1 | 2261 | 19700105 | 19700105 |
| E4657A | 2 | 1,460 | 1 | 446 | 19220804 | 19520814 |
| E4624A | 2 | 1,087 | 1 | 180 | 19150707 | 19760412 |
| Table Total | 53 | 2,493,451 | 14 | 6,316,330 | 19150707 | 30001231 |
| WAM Totall | 371 | 2,505,650 | 212 | 6,403,210 | 18711231 | 30001231 |

## 3.2 Neches River Basin

### 3.2.1 Description of the Basin

The Neches River Basin is located in east of Texas, as shown in Figure 3.5, and confined on the north and east by the Sabine River Basin, on the west by Trinity River Basin and on the south by the Neches-Trinity coastal basin. The drainage area of the Neches River Basin is about 10,000 square miles of which the drainage area of the Angelina River covers about one-third of the basin and the Neches River, Pine Island Bayou, and Village Creek covers two-thirds of the basin. The length of basin is about 200 miles. The Texas Water Development Board projected that the population of the Neches

River Basin, about 802,000 in 2010, will increase by 34% by the year 2030 (Wurbs *et al.*, 2014a). The mean annual precipitation is about 49 inches/year.

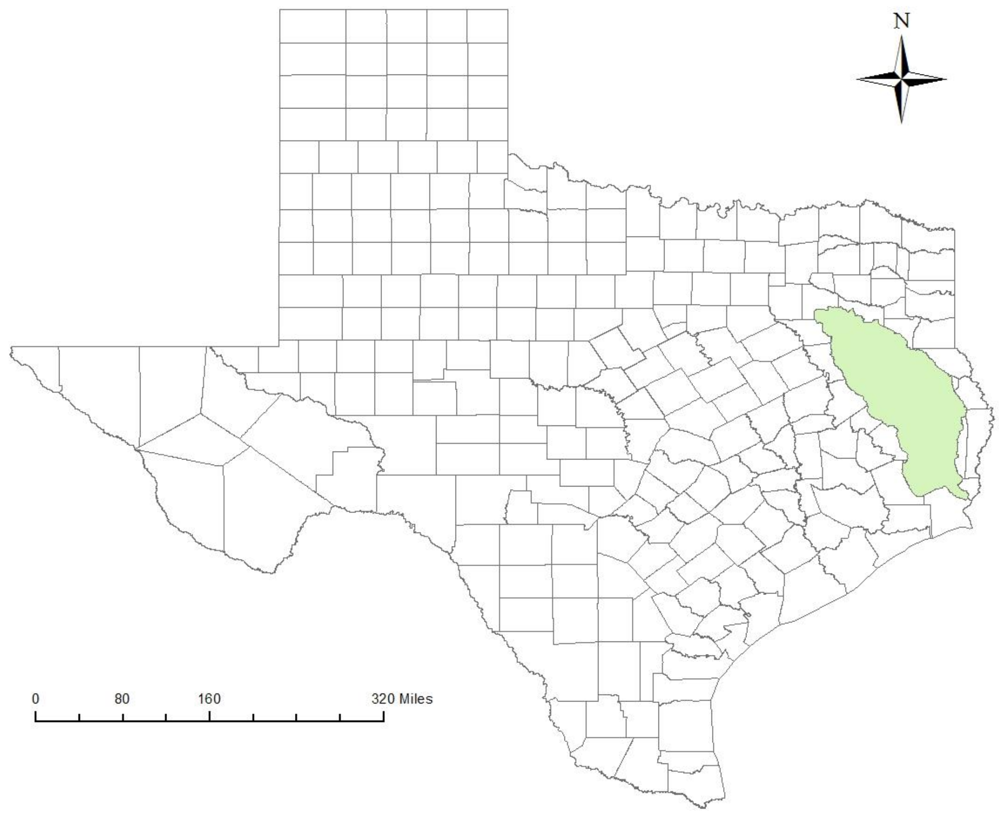



Figure 3.5 Location of Neches River Basin

3.2.2 Neches WAM

TCEQ contractors developed the original Neches WAM as documented by a 1999 report entitled *Neches River Basin Water Availability Study*. The TCEQ has periodically updated the Neches WAM water rights data files along with the WAMs for the other river basins of the state. The authorized use scenario Neches WAM dataset with latest TCEQ revisions dated October 1, 2012 was used for developing the daily WAM. The Neches

WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots neches3 and neches8, respectively. *WRAP-SIM* prints a listing to its message file of the number of various system components. The *SIM* counts in Table 3.6 are from the April 2010 and October 2012 Neches WAM full authorized use scenario and September 2012 current conditions scenario datasets.

Table 3.6 Number of System Components in Neches WAM Datasets

| Latest Update of Datasets<br>Water Use Scenario<br>Filename | Apr 2010<br>Authorized<br>neches3 | Oct 2012<br>Authorized<br>neches3 | Sep 2012<br>Current<br>neches8 |
|---|---|---|---|
| total number of control points | 306 | 378 | 395 |
| number of primary control points | 20 | 20 | 20 |
| control points with evaporation-precip. rates | 12 | 12 | 12 |
| number of reservoirs as counted by *SIM* | 180 | 180 | 203 |
| number of *WR* record water rights | 328 | 399 | 385 |
| number of instream flow *IF* record rights | 19 | 75 | 78 |
| number of system water rights | 9 | 29 | 26 |
| number of sets of water use *UC* records | 33 | 43 | 43 |
| number of *FD* records in DIS file | 273 | 273 | 289 |

*Control points*

Primary control points have monthly naturalized flow data on *IN* records in a FLO file in a *SIM* input dataset. However, the *SIM* simulation calculates naturalized flows at all other control points, called *secondary* control points based on the naturalized flows provided at the primary control points and watershed parameters.

There are 20 primary control points in the Neches WAM as listed in Table 3.7 with locations and connectivity shown in Figures 3.6 and 3.7. The 16 primary control points are mostly same locations of the sites of USGS stream gaging stations, and 4 primary control points NEPA, MUTY, ANSR, and NESL corresponded to the locations of reservoirs and the river basin outlet (Wurbs *et al.*, 2014b).

Table 3.7 Primary Control Points in the Neches WAM

| Control Point | USGS Gage No. | Location | Drainage Area |
|---|---|---|---|
| | | | (sq. miles) |
| KIBR | 08031200 | Kickapoo Creek near Brownsboro | 232 |
| NEPA | – | Neches River at Lake Palestine | 837 |
| NENE | 08032000 | Neches River near Neches | 1,145 |
| NEAL | 08032500 | Neches River near Alto | 1,943 |
| NEDI | 08033000 | Neches River near Diboll | 2,724 |
| NERO | 08033500 | Neches River near Rockland | 3,631 |
| MUTY | – | Mud Creek at Lakes Tyler and Tyler East Dams | 114 |
| MUJA | 08034500 | Mud Creek near Jacksonville | 376 |
| EFACU | 08033900 | East Fork Angelina River near Cushing | 157 |
| ANAL | 08036500 | Angelina River near Alto | 1,273 |
| ANLU | 08037000 | Angelina River near Lufkin | 1,601 |
| ATCH | 08038000 | Attoyac Bayou near Chireno | 504 |
| AYSA | 08039100 | Ayish Bayou near San Augustine | 89 |
| ANSR | – | Angelina River at Sam Rayburn Reservoir | 3,452 |
| NETB | 08040600 | Neches River near Town Bluff | 7,571 |
| NEEV | 08041000 | Neches River at Evadale | 7,885 |
| VIKO | 08041500 | Village Creek near Kountze | 861 |
| PISL | 08041700 | Pine Island Bayou near Sour Lake | 368 |
| NEBA | 08041780 | Neches River Saltwater Barrier at Beaumont | 9,826 |
| NESL | – | Neches River at Sabine Lake | 10,025 |


Figure 3.6 Map of Primary Control Points in the Neches WAM

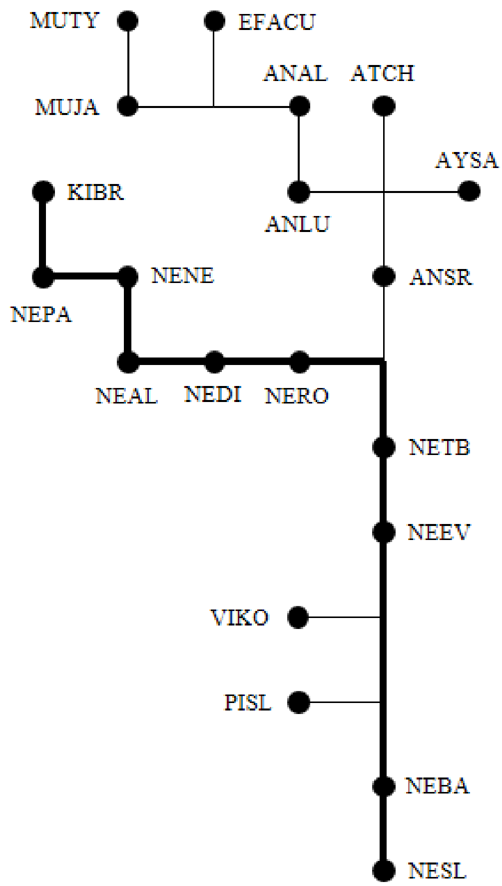



Figure 3.7 Schematic of Primary Control Points in the Neches WAM (Wurbs *et al.*, 2014b)

*Reservoirs*

Table 3.8 lists 11 existing reservoirs and two permitted but not yet constructed reservoirs in the Neches River Basin with storage capacities of greater than 5,000 acres with their authorized use scenario and current use scenario conservation storage capacities. Figure 3.8 shows their locations. There is the total permitted conservation storage capacity of 3,852,160 acre-feet of these 13 major reservoirs that captures 98.7 percent of the total storage capacity of 3,904,100 acre-feet in the 180 reservoirs in the October 2012 authorized use scenario Neches WAM. There are 203 reservoirs with a total conservation storage capacity of 3,656,259 acre-feet in the September 2012 current use scenario dataset.


Figure 3.8 Major Reservoirs in the Neches River Basin

Table 3.8 Major Reservoirs in the Neches River Basin

| Reservoir | Dam | Stream | Initial Impound | Reservoir Identifier | Conservation Capacity Authorized | Conservation Capacity Current |
|---|---|---|---|---|---|---|
| | | | | | (acre-feet) | (acre-feet) |
| Sam Rayburn | Sam Rayburn | Angelina River | 1965 | RAYBRN | 2,898,200 | 2,887,736 |
| B A Steinhagen | Town Bluff | Neches River | 1951 | STEINH | 94,250 | 66,972 |
| Palestine | Blackburn Crossing | Neches River | 1962 | PALEST | 411,840 | 403,825 |
| Tyler East | Mud Creek Dam | Mud Creek | 1966 | TYLERW | 43,100 | 36,158 |
| Tyler | Whitehouse Dam | Prairie Creek | 1949 | TYLERE | 44,000 | 44,000 |
| Athens | Athens | Flat Creek | 1962 | ATHENS | 32,840 | 29,475 |
| Jacksonville | Buckner | Gum Creek | 1957 | JACKSN | 30,500 | 30,239 |
| Striker Creek | Striker Creek | Striker Creek | 1957 | STRIKR | 26,960 | 22,618 |
| Kurth | Kurth (off-channel) | Angelina River | 1961 | KURTH | 16,200 | 14,600 |
| Pinkston | Pinkston | Sandy Creek | 1978 | PINKST | 7,380 | 7,349 |
| Nacogdoches | Nacogdoches | Bayo Loco Creek | 1976 | NACH | 42,318 | 39,427 |
| | | Proposed Projects Permitted but Not Yet Constructed | | | | |
| Columbia | Columbia | Mud Creek | − | COLUM | 195,500 | − |
| Naconiche | Naconiche | Naconiche Creek | − | NACKNK | 9,072 | 9,072 |

*Water rights*

A summary of the water rights in the October 2012 authorized use scenario dataset is listed in Table 3.9. Total permitted annual diversions are 1,730,431 acre-feet/year and these are allocated between types of use as follows: municipal (30.2%), industrial (43.4%), irrigation (25.7%), mining (0.07%), recreation (0.00%), and other (0.59%). The original 1999 WAM contained all of the water rights as listed in Table 3.9 with the exception of the addition of a water right with a diversion of 10,000 acre-feet/year and priority date of November 3, 2004.

Table 3.9 Water Rights Summary

| Type of Use | Number of Rights | Permitted Diversions (ac-ft/yr) | Range of Priority Dates from | to |
|---|---|---|---|---|
| municipal | 29 | 523,077 | 1915 | 2000 |
| industrial | 49 | 751,607 | 1914 | 1990 |
| irrigation | 119 | 444,189 | 1913 | 1994 |
| mining | 6 | 1,287 | 1948 | 1977 |
| recreation | 99 | 0 | 1900 | 2002 |
| other | 11 | 10,271 | 1969 | 2010 |
| total | 313 | 1,730,431 | | |

## 3.3 Guadalupe and San Antonio River Basins

### 3.3.1 Description of the Basins

The Guadalupe and San Antonio River (GSA) Basins are located in the southern part of Texas as shown in Figure 3.9. The Guadalupe River is the main stream, and the San Antonio River is the tributary of the Guadalupe River. The two rivers meet at a short distance upstream of Guadalupe Estuary and then flow into San Antonio Bay. The basin areas of the Guadalupe and San Antonio Rivers are 5,900 and 4,200 square miles each, for a combined total of 10,100 square miles. The two river basins are considered a single WAM because there are more than 30 percent of the total authorized consumptive diversion from the two rivers and their tributaries at the downstream of their confluence (Wurbs *et al.*, 2014b).

The lengths of the Guadalupe and San Antonio Rivers are about 230 miles long and about 240 miles long, respectively. The major tributaries of the Guadalupe River are the San Marcos River, Peach Creek, Sandies Creek, and Coleto Creek. The Blanco River and Plum Creek flow into the San Marcos River which flows into the Guadalupe River. The major tributaries of the San Antonio River are the Medina River, Leon Creek, Salado Creek, and Cibolo Creek. The range of average annual rainfall in the basins is from 39 inches near San Antonio Bay to 29 inches in the western portions of the basins. The

Edwards Aquifer, which significantly affects surface water availability through spring flows and recharge within the aquifer outcrop transects the basins.

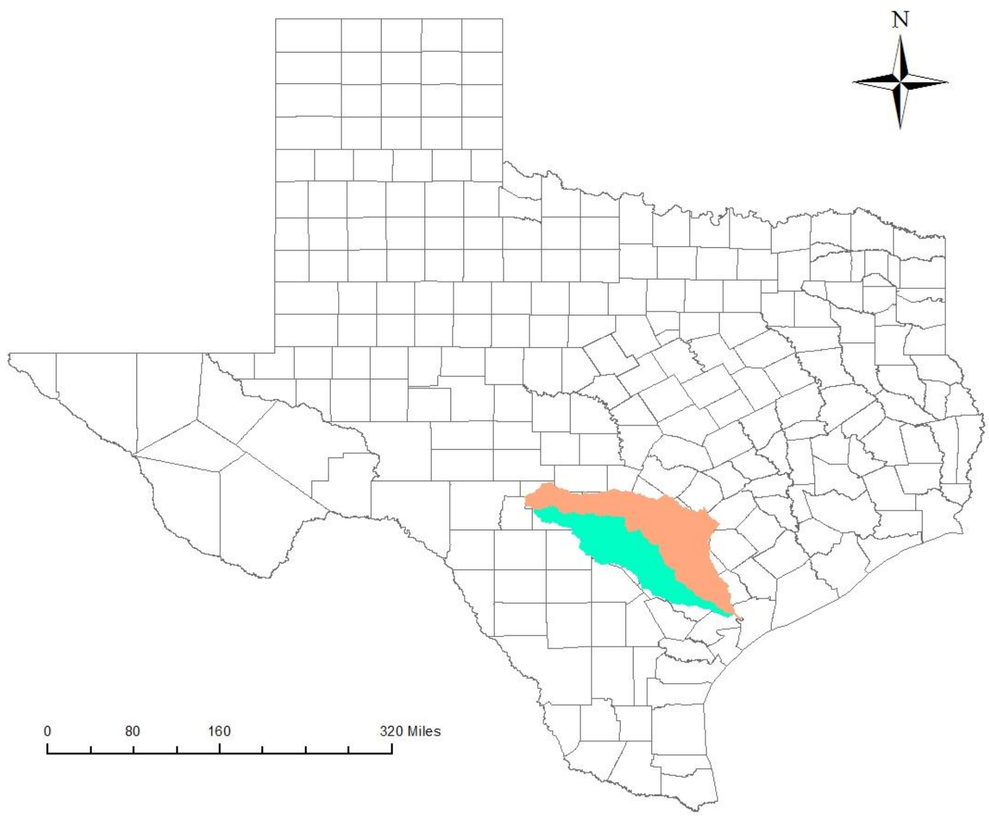



Figure 3.9 Location of Guadalupe and San Antonio River Basins

3.3.2 GSA WAM

Consulting firms working for the TCEQ developed the original Sabine WAM as documented by a 1999 report entitled *Water Availability in the GSA River Basin*. The TCEQ has periodically updated the GSA WAM water rights data files along with the WAMs for the other river basins of the state. The authorized use scenario Sabine WAM dataset with latest TCEQ revisions dated October 14, 2008 was used for developing the daily WAM. The GSA WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots gsa_run3 and gsa_run8, respectively. *WRAP-SIM* prints a listing to its message file of the number of various system components. The *SIM* counts in Table 3.10 are from the October 2008 GSA WAM full authorization and current conditions scenarios.

Table 3.10 Number of System Components in GSA WAM Datasets

| Latest Update of Datasets<br>Water Use Scenario<br>Filename | Oct 2008<br>Authorized<br>gsa_run3 | Oct 2008<br>Current<br>gsa_run8 |
|---|---|---|
| total number of control points | 1,338 | 1,340 |
| number of primary control points | 46 | 46 |
| control points with evaporation-precip. rates | 11 | 13 |
| number of reservoirs as counted by *SIM* | 238 | 241 |
| number of *WR* record water rights | 848 | 872 |
| number of instream flow *IF* record rights | 200 | 214 |
| number of system water rights | 21 | 22 |
| number of drought index *DI* records | 6 | 6 |
| number of *FD* records in DIS file | 1,209 | 1,211 |

*Control points*

There are 46 primary control points in the GSA WAM as shown in Table 3.11 and Figures 3.10 and 3.11, with monthly naturalized flows provided in the FLO file. Naturalized flows at over 1,290 secondary control points are computed during execution of *SIM* based on naturalized flow input datasets at primary control points and information provided in the DIS file. Thirty of the primary control points are located at the same location of USGS gaging stations. Gaged stream flows at Canyon Lake (CP03) and Calaveras Lake (CP31) include computed reservoir inflows. The Guadalupe River Basin has Twenty-two of the primary control points, including CP38 at the San Antonio River Confluence and CPEST at the outlet at the estuary, and the San Antonio River Basin has Twenty-four of the primary control points.

Table 3.11 Primary Control Points in the GSA WAM

| Control Point | USGS Gage No. | Location | Drainage Area (sq. miles) |
|---|---|---|---|
| | | Guadalupe River Basin | |
| CP01 | 08167000 | Guadalupe River at Comfort | 838 |
| CP02 | 08167500 | Guadalupe River near Spring Branch | 1,315 |
| CP03 | 08167800 | Guadalupe River at Canyon Lake | 1,432 |
| CP04 | 08168500 | Guadalupe River above Comal River at New Braunfels | 1,519 |
| CP05 | 08169000 | Comal River at New Braunfels | 130 |
| CP06 | − | Guadalupe River at Lake Wood | 2,103 |
| CP08 | 08171000 | Blanco River at Wimberley | 355 |
| CP09 | 08171300 | Blanco River near Kyle | 412 |
| CP10 | 08172000 | San Marcos River at Luling | 839 |
| CP11 | 08173000 | Plum Creek near Luling | 311 |
| CP12 | 08174600 | Peach Creek below Dilworth | 460 |
| CP13 | 08175000 | Sandies Creek near Westhoff | 549 |
| CP14 | 08175800 | Guadalupe River at Cuero | 4,935 |
| CP15 | 08176500 | Guadalupe River at Victoria | 5,196 |
| CP16 | 08177400 | Coleto Creek Reservoir near Victoria | 493 |
| CP38 | 08188800 | Guadalupe River near Tivoli | 10,122 |
| CP71 | − | Sink Creek | 43 |
| CP72 | − | Purgatory Creek | 34 |
| CP73 | − | York Creek | 12 |
| CP74 | − | Alligator Creek | 4 |
| CP75 | − | San Marcos Springs | 0.1 |
| CPEST | − | Guadalupe Estuary | 10,122 |
| | | San Antonio River Basin | |
| CP17 | − | Olmos Creek at Edwards | 8 |
| CP18 | 08178000 | San Antonio River at San Antonio | 44 |
| CP19 | 08178700 | Salado Creek at San Antonio Upper Station | 136 |
| CP20 | 08178800 | Salado Creek at San Antonio Lower Station | 187 |
| CP21 | 08179500 | Medina Lake | 634 |
| CP22 | − | Tributaries to Diversion Lake | 16 |
| CP23 | 08180500 | Medina River near Rio Medina | 649 |
| CP241 | − | West Tributaries downstream of Diversion Lake | 4 |
| CP242 | − | East Tributaries downstream of Diversion Lake | 7 |
| CP25 | − | San Geronimo Creek at Edwards | 58 |
| CP261 | − | Leon Creek at Edwards | 60 |
| CP262 | − | Helotes Creek at Edwards | 28 |
| CP263 | − | Government Creek at Edwards | 12 |
| CP27 | 08180800 | Medina River near Somerset | 962 |
| CP28 | 08181500 | Medina River at San Antonio | 1,310 |

Table 3.11 (Continued)

| Control Point | USGS Gage No. | Location | Drainage Area |
|---|---|---|---|
| CP29 | 08181800 | San Antonio River near Elmendorf | 1,737 |
| CP30 | – | Braunig Lake | 9 |
| CP31 | 08182500 | Calaveras Lake | 65 |
| CP32 | 08183500 | San Antonio River near Falls City | 2,108 |
| CP33 | 08183900 | Cibolo Creek near Boerne | 68 |
| CP34 | 08185000 | Cibolo Creek at Selma | 274 |
| CP35 | 08186000 | Cibolo Creek near Falls City | 825 |
| CP36 | 08186500 | Ecleto Creek near Runge | 239 |
| CP37 | 08188500 | San Antonio River at Goliad | 3,906 |

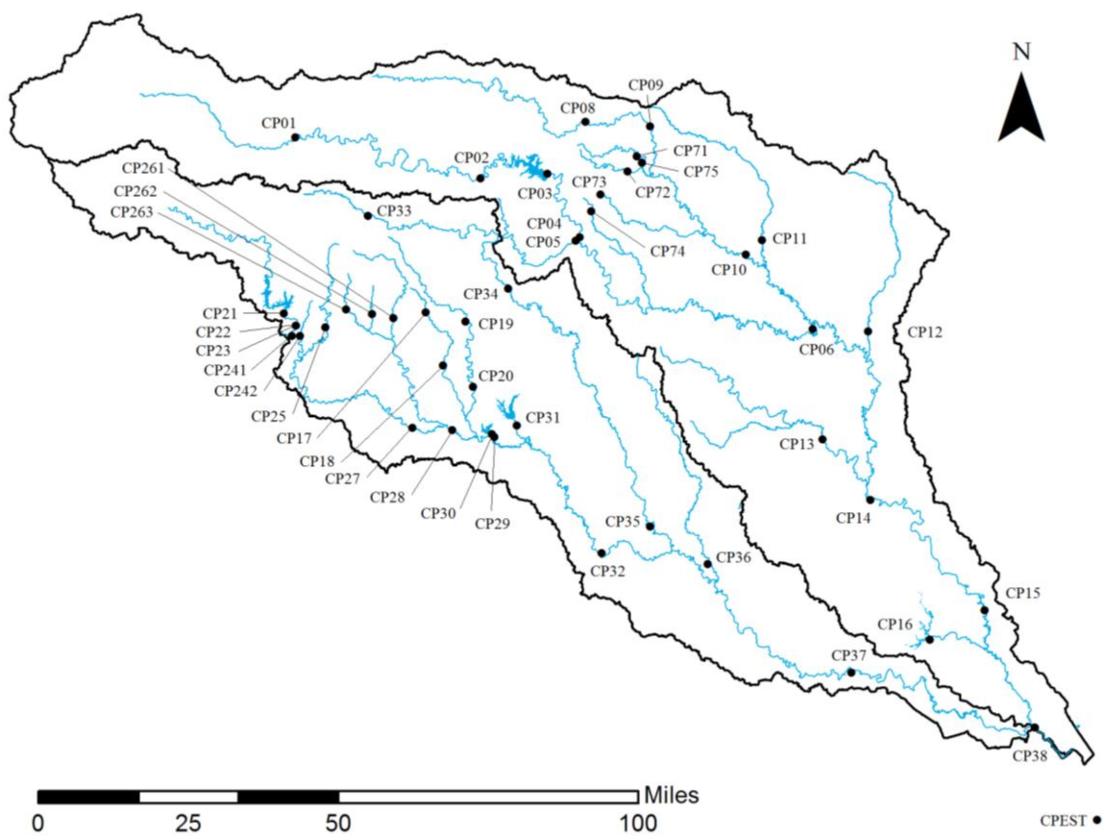



Figure 3.10 Map of Primary Control Points in the GSA WAM (Wurbs *et al.*, 2014c)

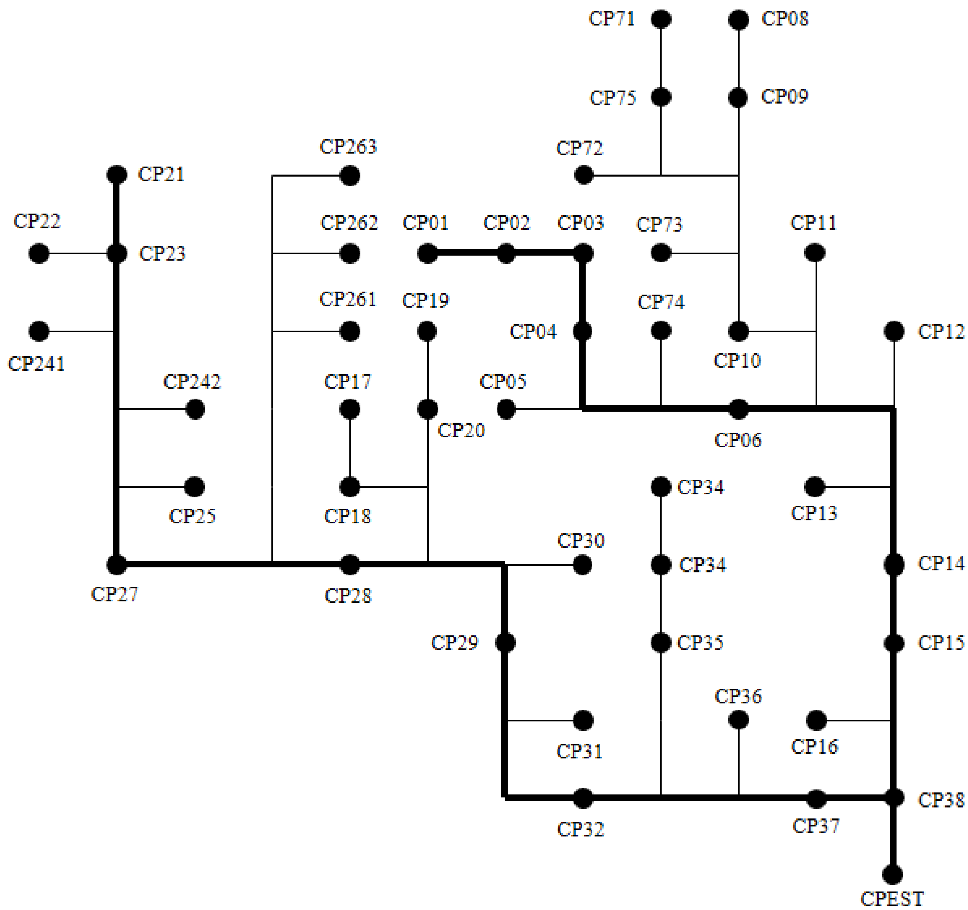



Figure 3.11 Schematic of Primary Control Points in the GSA WAM (Wurbs *et al.*, 2014c)

<u>*Reservoirs*</u>

Table 3.12 lists the nine largest of the 238 reservoirs included in the October 2008 authorized use scenario GSA WAM. There are 229 smaller reservoirs with storage capacities of 1,400 acre-feet or less in GSA WAM. The total permitted conservation storage capacity of 775,868 acre-feet of the 9 major reservoirs capture 96.1 percent of the total storage capacity of 806,875 acre-feet in the 238 reservoirs. Figure 3.12 shows the locations of nine major reservoirs. Canyon Lake cited in Table 3.12 does not contain the 394,900 acre-feet flood control pool which is not included in the WAM.

Table 3.12 Major Reservoirs in the GSA WAM

| No. | Reservoir | Stream | Identifier | Control Point | Authorized Capacity (acre-feet) |
|---|---|---|---|---|---|
| 1 | Canyon Lake | Guadalupe River | CANYON | 207401 | 386,200 |
| 2 | Medina Lake | Medina River | MEDINA | CP21 | 237,875 |
| 3 | Calaveras Lake | Calaveras Creek | CALVER | 216231 | 63,200 |
| 4 | Coleto Creek Reservoir | Coleto Creek | COLETO | 548631 | 35,084 |
| 5 | Victor Braunig Lake | Arroyo Seco | BRAUNG | 216131 | 26,500 |
| 6 | Olmos Reservoir | Olmos Creek | R3898 | P38981 | 14,240 |
| 7 | Cooling Reservoir | | R5178 | 517801 | 4,770 |
| 8 | Boerne Lake | Cibolo Creek | BOERNE | 114302 | 4,046 |
| 9 | Diversion Lake | Medina River | DIVERS | CP23 | 3,953 |

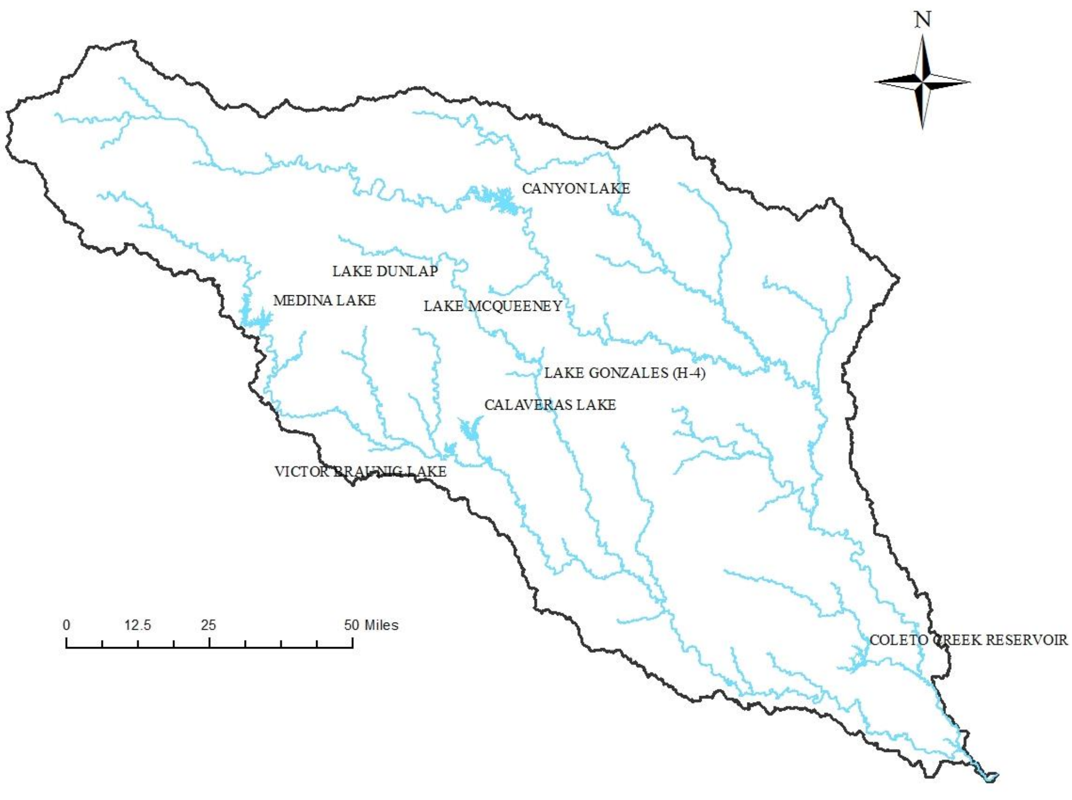



Figure 3.12 Major Reservoirs in the GSA River Basins

*Water rights*

There are 604 water rights having priority dates senior to August 1998 authorizing total annual diversions of 6,378,964 acre-feet/year which includes total consumptive use of 558,430 acre-feet/year in the original GSA WAM, as summarized in Table 3.13.

Flows of the Guadalupe River for generating hydroelectric energy, modeled as diversions with 100% return flows, captures 83.1 percent of the total diversions in the GSA WAM. The largest water rights in the Guadalupe River Basin and the largest water rights in the San Antonio River Basin are listed in Tables 3.14 and 3.15, respectively.

Table 3.13 Summary of Diversion Rights in the GSA WAM

| | Guadalupe River Basin | | San Antonio River Basin | |
|---|---|---|---|---|
| Type of Use | Authorized Diversions | Authorized Consumptive | Authorized Diversions | Authorized Consumptive |
| | (ac-ft/yr) | (ac-ft/yr) | (ac-ft/yr) | (ac-ft/yr) |
| Municipal | 201,820 | 201,820 | 34,967 | 34,967 |
| Industrial | 592,324 | 87,862 | 53,436 | 53,436 |
| Irrigation | 89,121 | 89,121 | 88,656 | 88,656 |
| Mining | 153 | 30 | 4,504 | 600 |
| Hydroelectric | 5,303,585 | 0 | 0 | 0 |
| Recreation | 6,648 | 8 | 1,190 | 0 |
| Other | 1,600 | 970 | 0 | 0 |
| Recharge | 0 | 0 | 961 | 961 |
| Total | 6,195,250 | 379,810 | 183,714 | 178,620 |

Table 3.14 includes the 14 water rights in the Guadalupe Basin with authorized diversions of 20,000 acre-feet/year or greater. These 14 rights comprise 97.8 percent of the total authorized diversions and 74.8 percent of the total authorized consumptive use in the Guadalupe Basin. The Guadalupe Blanco River Authority (GBRA) has the first three water rights (5488, 5172, 2074) in Table 3.14 and capture 59.8 percent of the total authorized diversion in the GSA WAM.

Table 3.14 Largest Water Rights in the Guadalupe River Basin

| Water Right | Owner | Diversion Rights | Consumptive Rights | Storage Rights |
|---|---|---|---|---|
| | | (ac-ft/yr) | (ac-ft/yr) | (ac-ft) |
| 5488 | GBRA | 2,603,991 | 0 | 0 |
| 5172 | GBRA | 1,160,431 | 0 | 0 |
| 2074 | GBRA | 50,000 | 50,000 | 740,900 |
| 5178 | GBRA & Union Carbide | 106,000 | 106,000 | 4,770 |
| 5177 | GBRA & Union Carbide | 51,247 | 51,247 | 0 |
| 3846 | City of Gonzales | 798,603 | 2,240 | 1,400 |
| 3853 | Cuero Hydroelectric, Inc. | 538,560 | 0 | 808 |
| 3824 | New Braunfels Utilities | 266,508 | 5,858 | 150 |
| 5485 | Central Power and Light | 209,189 | 0 | 0 |
| 3859 | South Texas Electric | 110,000 | 1,900 | 20 |
| 3865 | Texas State University | 66,217 | 1,217 | 150 |
| 3861 | E.I. DuPont DeNemours | 60,000 | 33,000 | 1,056 |
| 5486 | Central Power and Light | 20,000 | 12,500 | 35,084 |
| 5466 | City of Victoria | 20,000 | 20,000 | 1,000 |

Table 3.15 Largest Water Rights in the San Antonio River Basin

| Water Right | Owner | Diversion Rights | Consumptive Rights | Storage Rights |
|---|---|---|---|---|
| | | (ac-ft/yr) | (ac-ft/yr) | (ac-ft) |
| 2130 | Bexar-Medina-Atascosa WCID | 66,750 | 66,750 | 242,374 |
| 2162 | City of San Antonio | 60,000 | 37,000 | 63,200 |
| 5517 | City of San Antonio | 12,000 | 12,000 | 26,500 |
| 4768 | Leon Creek WSC | 7,500 | 7,500 | 1,000 |
| 4768 | Bexar Metropolitan Wat Dist | 5,000 | 5,000 | 595 |
| 5211 | Lone Star Growers Co. | 3,000 | 3,000 | 458 |
| 5549 | Bexar Metropolitan Wat Dist | 2,250 | 2,250 | 148 |

CHAPTER IV

# INFILLING MISSING NATURALIZED FLOWS USING THE SWAT MODEL

## 4.1 Procedure

The primary control points having monthly naturalized flow datasets are adopted from the WAM datasets of the Sabine, Neches, and GSA River Basins in order to explore the validity and effectiveness of flow synthesis methods proposed in this research. Certain sub-periods of the periods-of-analysis of the naturalized flow datasets are treated as having no flow data and called the "missing period." Other sub-periods of the datasets are called the "recorded period" and are treated as having recorded data.

The monthly SWAT models are developed at each primary control point with GIS data such as DEM, land cover and use, soil type and the location of each primary control point. The selected parameters of these SWAT models are calibrated with the naturalized flow data for recorded period after initial simulations with inputted rainfall data and generated weather data. The calibrated SWAT models generate the flow sequences during the missing period at each primary control point. MOVE2 is applied to transfer the flow sequences to fill in gaps of missing periods based on flow sequences synthesized with the SWAT model.

The method performance is finally evaluated through comparative analysis with naturalized datasets for assumed missing periods. The comparative analysis includes statistical and flow frequency evaluations. Figure 4.1 is a flowchart summarizing the methodology for synthesizing missing naturalized flows using the SWAT model.

## 4.2 Data

### 4.2.1 Selected Naturalized Flow Datasets

In general, naturalized flow datasets in the WAM system were developed based on adjusting USGS recorded flow data using Equation 1.1. If the recorded data at a control point has some missing period, this missing period was filled by a linear transfer method based on the data for the same period at a near control point. These WAM datasets could possibly have some statistical bias in the flow sequences. Thus, the primary control points that have naturalized flow datasets made based on only USGS recorded data without any missing periods are being selected from the three WAM datasets for more accurate evaluation of the proposed method in this research.

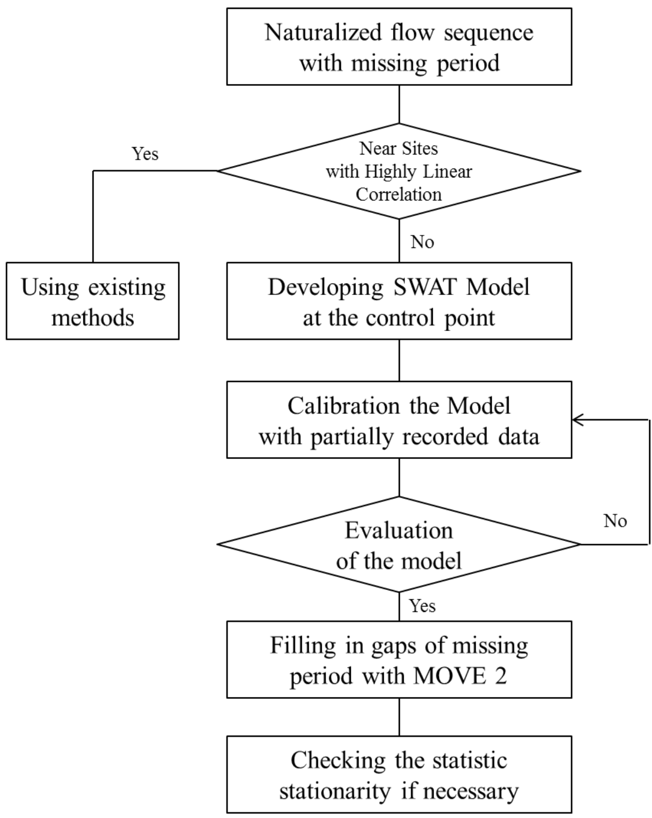



Figure 4.1 Flowchart for Infilling Missing Naturalized Flows Using the SWAT Model

Table 4.1 lists the selected primary control points from the three river basin WAM datasets, and these locations are referred to in the figures in the Chapter III. Seventeen primary control points are chosen, including 6 primary control points from the Sabine River Basin, 5 primary control points from the Neches River Basin, and 6 primary control points from the GSA River Basins, respectively.

The selected control points are well-distributed within each river basin, covering upstream and downstream. The watershed areas of these primary control points range from 130 square miles (CP05 in the GSA River Basins) as a minimum to 9,329 square miles (SRRL in the Sabine River Basin) as a maximum. The flow characteristics are very different from each other depending on the location of the control points. For example, control point CP05 has a small drainage area but relatively great base flows due to a spring water source. The periods-of-analysis of the basins are 1940-1998 for the Sabine River Basin, 1940-1996 for the Neches River basin, and 1934-1989 for the GSA River Basins, respectively, as listed in Table 4.1.

Table 4.1 Selected Primary Control Points from the Basins

| Control Point | Location | Gage Number | Watershed Area ($mile^2$) | Period of Record |
|---|---|---|---|---|
| Sabine River Basin (Period of Analysis: 1940 to 1998) | | | | |
| LFQT | Lake Fork Creek near Quitman, TX | 8019000 | 585 | 7/24-4/26, 3/39 to present |
| BSBS | Big Sandy Creek near Big Sandy, TX | 8019500 | 231 | 02/39 to present |
| SRGW | Sabine River near Gladewater, TX | 8020000 | 2,791 | 10/32 to present |
| SRBE | Sabine River near Beckville, TX | 8022040 | 3,589 | 10/38 to present |
| SRBW | Sabine River near Bon Wier, TX | 8028500 | 8,229 | 10/23 to present |
| SRRL | Sabine River near Ruliff, TX | 8030500 | 9,329 | 10/24 to present |
| Neches River Basin (Period of Analysis: 1940 to 1996) | | | | |
| ATCH | Attoyac Bayou near Chireno, TX | 8038000 | 504 | 2/24-9/25,08/39 to present |
| NEEV | Neches River at Evadale, TX | 8041000 | 7,885 | 08/04 to present |
| NENE | Neches River near Neches, TX | 8032000 | 1,145 | 02/39 to present |
| NERO | Neches River near Rockland, TX | 8033500 | 3.631 | 07/03 to present |
| VIKO | Village Creek near Kountze, TX | 8041500 | 861 | 01/24 to present |
| GSA River Basins (Period of Analysis: 1934 to 1989) | | | | |
| CP02 | Guadalupe River near Spring Branch | 8167500 | 1,315 | 01/34 to present |
| CP04 | Guadalupe River at New Braunfels | 8168500 | 1,519 | 12/27 to present |
| CP05 | Comal River at New Braunfels | 8169000 | 130 | 12/27 to present |
| CP08 | Blanco River at Wimberley | 8171000 | 355 | 01/34 to present |
| CP32 | San Antonio River near Falls City | 8183500 | 2,108 | 05/25 to present |
| CP35 | Cibolo Creek near Falls City | 8186000 | 825 | 10/30 to present |

4.2.2 Precipitation

It is very important to obtain as many rain gauges as possible with data for the long term period for the SWAT simulation. Hernandez *et al.* (2000) highlighted that improvements in the results of estimated streamflow could be expected by increasing the number of rain gauges. The spatial distribution of rain gauges within a basin is also important. Inadequate spatial coverage of precipitation inputs would lead to some of the poorer results in previous SWAT studies (Cao *et al.*, 2006; Conan *et al.*, 2003; Bouraoui *et al.*, 2002; Bouraoui *et al.*, 2005).

The National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) provides climatic data including precipitation on the Website: http://www.ncdc.noaa.gov/cdo-eb/search;jsessionid=113467DB762EC09682895783A8FFCDB2. The climate data can be obtained from the web site based on the administrative, hydrologic, and climate regions. The data period can be also determined.

The measured precipitation data among various weather data such as temperature, wind speed, sun shine hours, etc. are used only in this research because the three river basins don't have snow melt issues. The SWAT model can generate other weather data that are needed for the simulation based on the weather database by its own weather generator. The ideal condition is that the periods of the collected data should cover the period-of-analysis of WAM datasets for the SWAT model, but most rain gauges don't have the desirable period of data. Although the SWAT model can fill in gaps of missing period with weather generator, the rain gauges with long term period data are collected considering spatial distribution within a basin as long as possible. Tables 4.2, 4.3, and 4.4 list the rain gauges for the three basin SWAT models in this research. The locations of the gauges are as shown in Figures 4.2, 4.3, and 4.4, respectively. These rain gauges will serve the SWAT models for the disaggregation of monthly flow to daily later in this research as well.

Table 4.2 List of Rain Gauges for the Sabine River Basin

| No. | Name | Latitude | Longitude | Elevation |
|---|---|---|---|---|
| 1 | USW00013972 | 32.354 | -95.403 | 165.800 |
| 2 | USC00162023 | 31.750 | -93.700 | 67.100 |
| 3 | USC00162367 | 30.843 | -93.287 | 57.900 |
| 4 | USC00164288 | 31.375 | -93.391 | 128.000 |
| 5 | USC00165266 | 31.142 | -93.240 | 8.500 |
| 6 | USC00165522 | 31.967 | -94.000 | 57.900 |
| 7 | USC00165527 | 31.983 | -93.950 | 64.000 |
| 8 | USC00165892 | 31.577 | -93.482 | 77.700 |
| 9 | USC00410611 | 30.097 | -94.100 | 6.100 |
| 10 | USC00410917 | 30.733 | -93.650 | 27.100 |
| 11 | USC00411425 | 32.563 | -95.877 | 149.400 |
| 12 | USC00411500 | 32.162 | -94.340 | 93.000 |
| 13 | USC00411578 | 31.808 | -94.164 | 99.100 |
| 14 | USC00411921 | 33.200 | -95.928 | 167.600 |
| 15 | USC00413000 | 30.333 | -94.083 | 10.100 |
| 16 | USC00413546 | 32.746 | -95.050 | 118.900 |
| 17 | USC00413565 | 32.517 | -94.967 | 85.000 |
| 18 | USC00413734 | 33.168 | -96.098 | 166.100 |
| 19 | USC00413846 | 33.333 | -95.233 | 107.000 |
| 20 | USC00414020 | 32.578 | -95.203 | 102.100 |
| 21 | USC00414081 | 32.181 | -94.796 | 128.000 |
| 22 | USC00414563 | 30.915 | -94.010 | 88.400 |
| 23 | USC00414819 | 30.617 | -93.917 | 61.000 |
| 24 | USC00415094 | 33.035 | -96.486 | 155.400 |
| 25 | USC00415341 | 32.473 | -94.717 | 100.600 |
| 26 | USC00415618 | 32.540 | -94.351 | 107.300 |
| 27 | USC00415766 | 33.236 | -96.642 | 189.600 |
| 28 | USC00415956 | 32.717 | -95.367 | 117.300 |
| 29 | USC00416177 | 31.616 | -94.643 | 132.600 |
| 30 | USC00416265 | 31.667 | -94.150 | 98.100 |
| 31 | USC00416664 | 30.086 | -93.742 | 3.000 |
| 32 | USC00416722 | 32.267 | -94.983 | 152.400 |
| 33 | USC00417271 | 32.117 | -94.967 | 113.100 |
| 34 | USC00417363 | 32.783 | -95.433 | 114.300 |
| 35 | USC00417707 | 32.933 | -96.465 | 165.500 |
| 36 | USC00419068 | 31.175 | -93.565 | 57.900 |
| 37 | USC00419214 | 32.400 | -95.267 | 149.000 |
| 38 | USC00419734 | 31.017 | -93.717 | 54.900 |
| 39 | USC00419800 | 32.702 | -96.015 | 158.500 |
| 40 | USC00419836 | 32.889 | -95.333 | 130.800 |

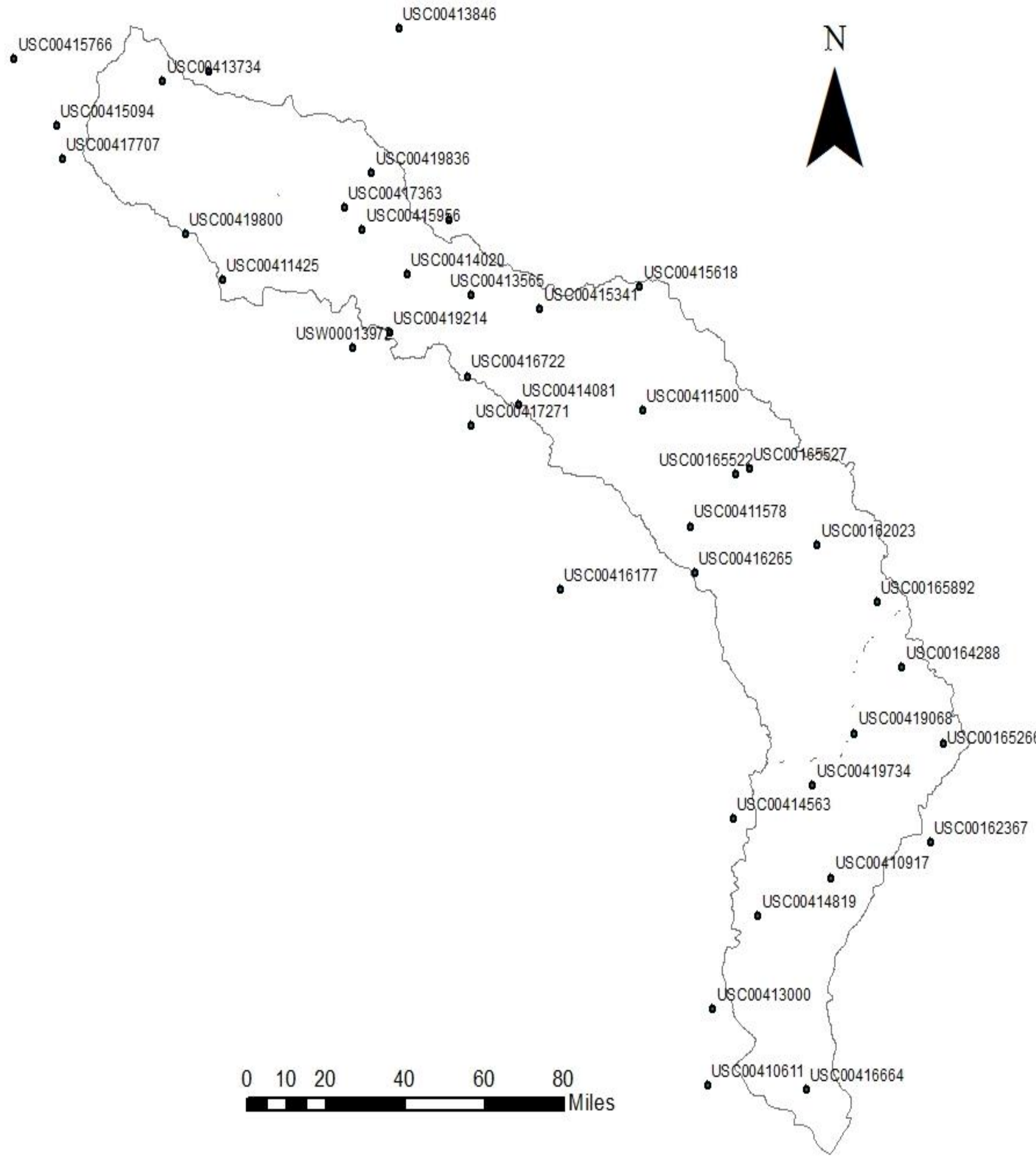



Figure 4.2 Map of Rain Gauges for the Sabine River Basin

Table 4.3 List of Rain Gauges for the Neches River Basin

| No. | Name | Latitude | Longitude | Elevation |
|---|---|---|---|---|
| 1 | USW00012917 | 29.950 | -94.017 | 9.100 |
| 2 | USW00013972 | 32.367 | -95.400 | 157.000 |
| 3 | USW00093914 | 31.783 | -95.600 | 141.700 |
| 4 | USW00093987 | 31.233 | -94.750 | 89.000 |
| 5 | USC00410190 | 31.600 | -95.150 | 78.900 |
| 6 | USC00410404 | 32.217 | -95.850 | 149.000 |
| 7 | USC00410611 | 30.083 | -94.100 | 6.100 |
| 8 | USC00411089 | 31.317 | -94.283 | 82.000 |
| 9 | USC00411425 | 32.563 | -95.877 | 149.400 |
| 10 | USC00411578 | 31.808 | -94.164 | 99.100 |
| 11 | USC00412114 | 31.317 | -95.467 | 107.000 |
| 12 | USC00412444 | 31.867 | -95.250 | 177.100 |
| 13 | USC00413000 | 30.350 | -94.083 | 11.900 |
| 14 | USC00414081 | 32.150 | -94.800 | 153.000 |
| 15 | USC00414525 | 31.967 | -95.283 | 159.100 |
| 16 | USC00414563 | 30.933 | -94.000 | 88.100 |
| 17 | USC00414819 | 30.617 | -93.917 | 61.000 |
| 18 | USC00415196 | 30.050 | -94.817 | 11.900 |
| 19 | USC00415271 | 30.700 | -94.950 | 57.900 |
| 20 | USC00416177 | 31.600 | -94.583 | 107.000 |
| 21 | USC00416722 | 32.267 | -94.983 | 152.400 |
| 22 | USC00417040 | 31.250 | -93.967 | 88.100 |
| 23 | USC00417547 | 31.900 | -94.983 | 100.600 |
| 24 | USC00417700 | 31.017 | -94.417 | 39.900 |
| 25 | USC00417841 | 31.800 | -95.150 | 149.000 |
| 26 | USC00417936 | 31.067 | -94.100 | 57.900 |
| 27 | USC00417951 | 31.533 | -94.117 | 100.900 |
| 28 | USC00419101 | 30.800 | -94.183 | 65.200 |
| 29 | USC00419734 | 31.017 | -93.717 | 54.900 |
| 30 | USC00419754 | 30.550 | -94.450 | 61.000 |
| 31 | USC00419800 | 32.702 | -96.015 | 158.500 |

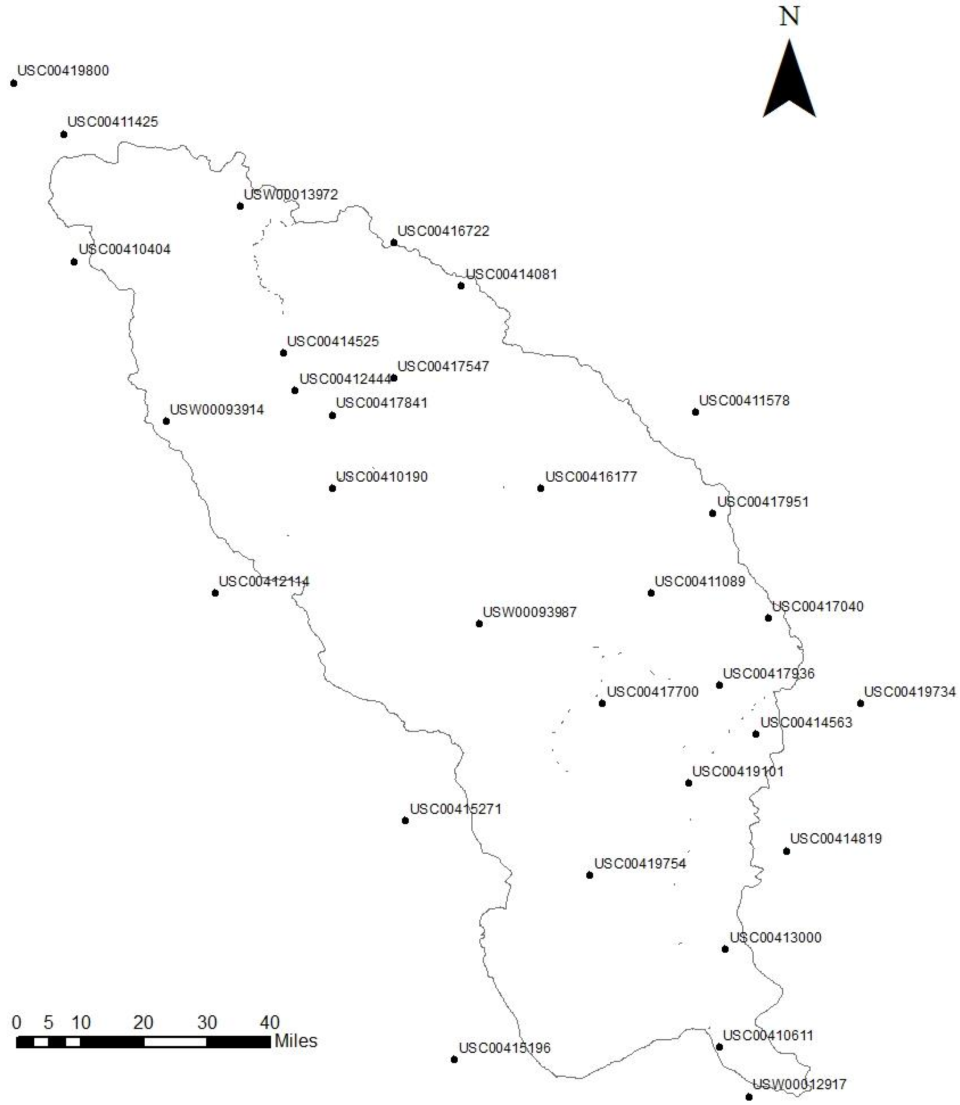



Figure 4.3 Map of Rain Gauges for the Neches River Basin

Table 4.4 List of Rain Gauges for the GSA River Basins

| No. | Name | Latitude | Longitude | Elevation |
|---|---|---|---|---|
| 1 | USW00012921 | 29.533 | -98.467 | 241.100 |
| 2 | USC00417628 | 29.467 | -98.867 | 289.900 |
| 3 | USC00413065 | 28.950 | -98.067 | 92.000 |
| 4 | USC00417836 | 28.867 | -97.717 | 95.100 |
| 5 | USC00413618 | 28.667 | -97.383 | 49.100 |
| 6 | USC00410902 | 29.817 | -98.750 | 430.100 |
| 7 | USC00418845 | 29.650 | -99.250 | 442.000 |
| 8 | USC00419813 | 29.900 | -99.600 | 694.900 |
| 9 | USC00418658 | 29.300 | -97.967 | 146.000 |
| 10 | USC00413201 | 29.133 | -98.150 | 118.900 |
| 11 | USC00411215 | 29.750 | -98.450 | 335.900 |
| 12 | USC00417215 | 29.050 | -98.567 | 189.000 |
| 13 | USC00410639 | 28.450 | -97.700 | 67.100 |
| 14 | USC00410509 | 30.133 | -98.817 | 533.400 |
| 15 | USC00410832 | 30.100 | -98.417 | 412.100 |
| 16 | USC00411671 | 29.267 | -97.400 | 75.900 |
| 17 | USC00412040 | 30.167 | -99.133 | 681.200 |
| 18 | USC00412173 | 29.083 | -97.250 | 57.900 |
| 19 | USC00413156 | 29.983 | -98.267 | 353.900 |
| 20 | USC00413183 | 29.683 | -97.133 | 131.100 |
| 21 | USC00413622 | 29.500 | -97.450 | 92.000 |
| 22 | USC00414375 | 30.050 | -99.517 | 638.600 |
| 23 | USC00414575 | 29.817 | -97.317 | 139.900 |
| 24 | USC00414780 | 30.033 | -99.133 | 502.900 |
| 25 | USC00415284 | 29.900 | -97.700 | 159.100 |
| 26 | USC00415429 | 29.667 | -97.633 | 121.900 |
| 27 | USC00416276 | 29.700 | -98.117 | 220.100 |
| 28 | USC00416368 | 29.267 | -97.767 | 121.900 |
| 29 | USC00417983 | 29.850 | -97.950 | 186.500 |
| 30 | USC00418186 | 29.550 | -97.967 | 171.000 |
| 31 | USC00418544 | 29.867 | -98.383 | 305.100 |
| 32 | USC00419365 | 28.800 | -97.017 | 9.100 |
| 33 | USC00419953 | 28.983 | -97.500 | 82.300 |

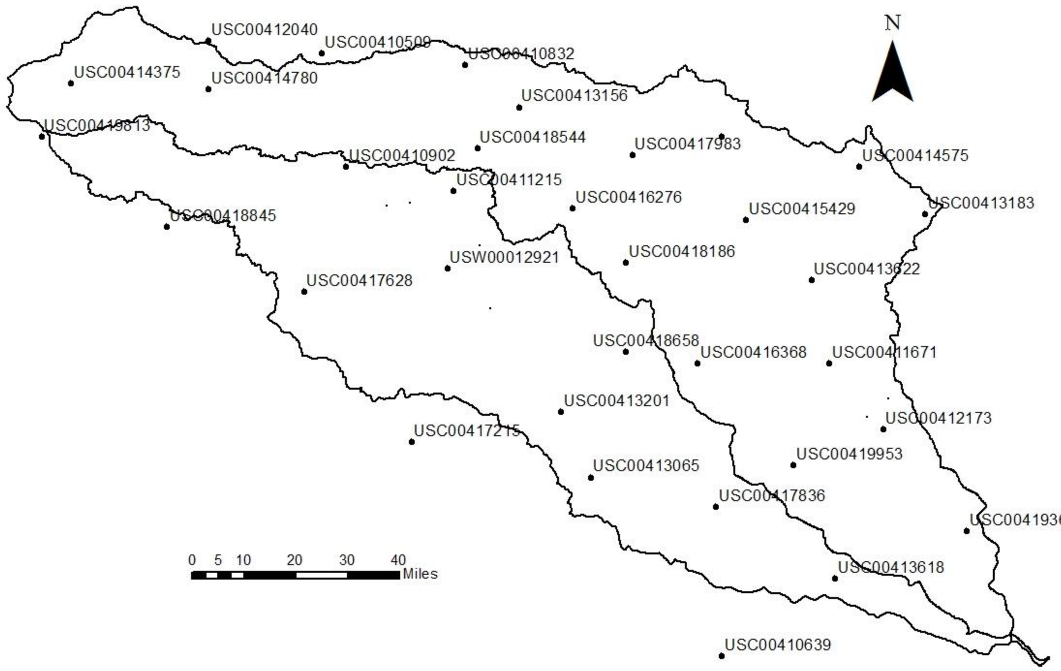



Figure 4.4 Map of Rain Gauges for GSA River Basins

### 4.2.3 GIS Data

The SWAT model needs GIS data such as DEM, land use, and soil map for delineating a watershed and for extracting spatially distributed hydrologic and topographic parameters. The SWAT model includes soil map (STATSGO) only in the U.S. Accordingly, DEMs with 30 m resolution and 2001 land cover map are obtained from the NRCS website for this research.

TCEQ also provides GIS data including the location of control points in WAM system through the TCEQ website. These GIS data will be used for the SWAT models for disaggregation of monthly flow to daily later like rain data in this research.

## 4.3 SWAT Model

### 4.3.1 Watershed Delineation

ArcSWAT provides a visual user interface for SWAT modeling within ArcGIS. The SWAT2012 with 2010 ArcGIS version is used in this research. Most of all, SWAT model delineates 17 watersheds for 17 primary control points with DEMs and the location data of primary control points using the watershed delineator. Next, the model determines HRUs with land use and soil data in sub-watersheds of a watershed. SWAT finally writes input tables with input rainfall data, weather generator and hydrologic and topographic parameters. Each SWAT model automatically chooses the nearest rain gauges based on the spatial locations from the input rainfall data.

The variation in HRU and/or sub-watershed delineations for watersheds generally affects streamflow prediction by SWAT model (Gassman *et al.*, 2007). In other words, the SWAT model should have a proper number of subwatersheds and HRUs in each subwatershed for more accurate streamflow prediction. Thus, all watersheds are delineated to have at least 15 subwatersheds and multiple HRUs in each subwatershed in each SWAT model. SWAT uses a daily computational time step, but daily results can be aggregated to monthly. The periods of simulation are different depending on the period-of-analysis in each basin WAM. The watershed delineations for each SWAT model are as shown in Figures 4.5 to 4.21.

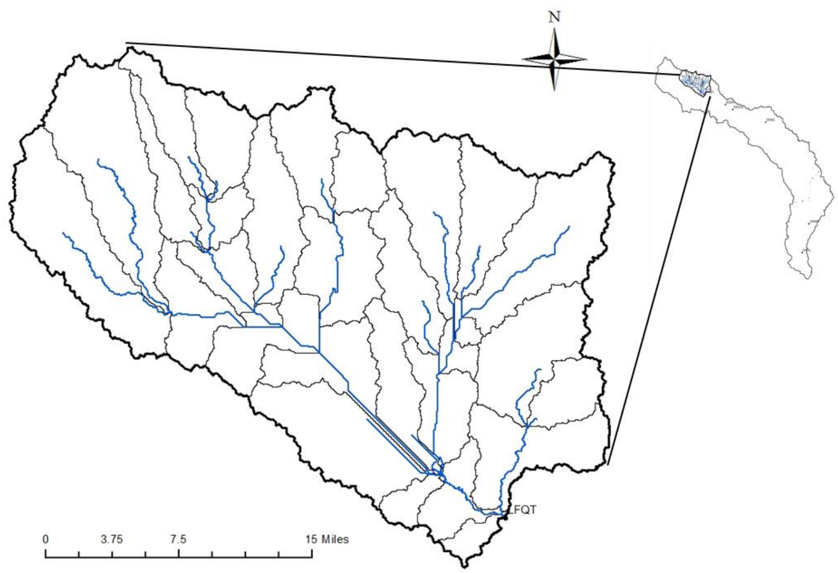



Figure 4.5 SWAT Model Watershed Delineation at LFQT in the Sabine River Basin

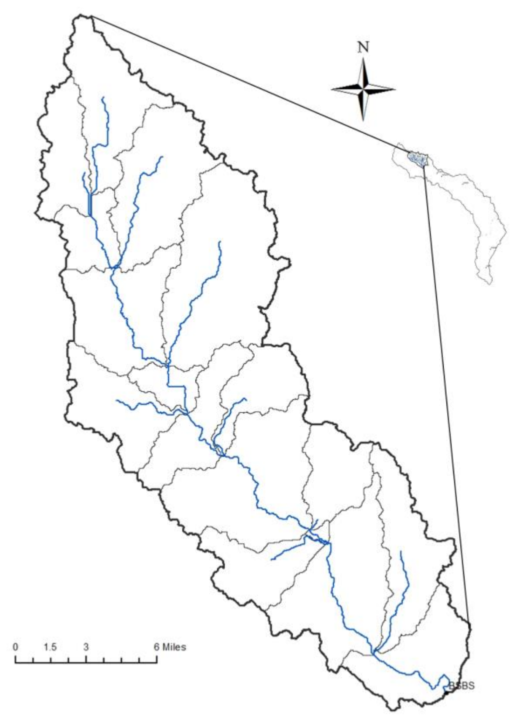



Figure 4.6 SWAT Model Watershed Delineation at BSBS in the Sabine River Basin

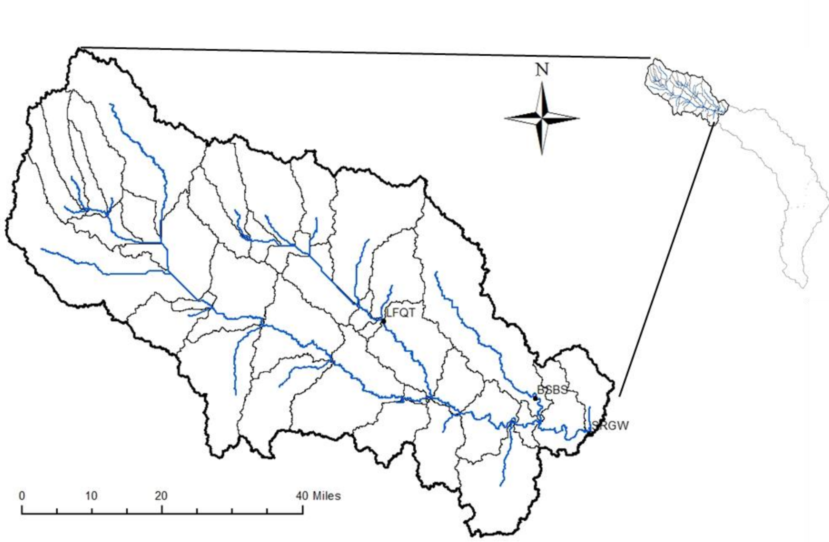



Figure 4.7 SWAT Model Watershed Delineation at SRGW in the Sabine River Basin

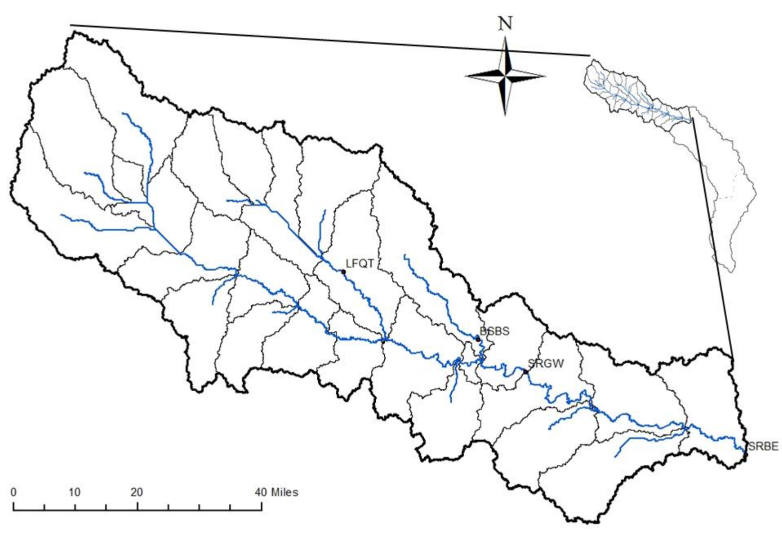



Figure 4.8 SWAT Model Watershed Delineation at SRBE in the Sabine River Basin

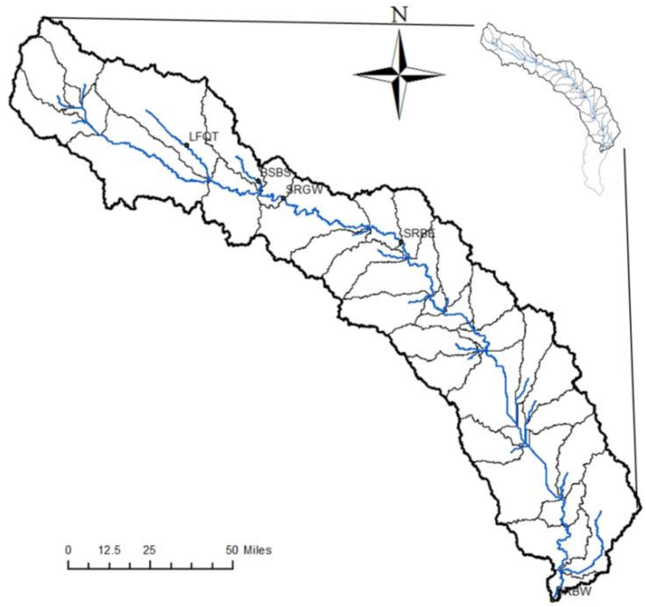



Figure 4.9 SWAT Model Watershed Delineation at SRBW in the Sabine River Basin

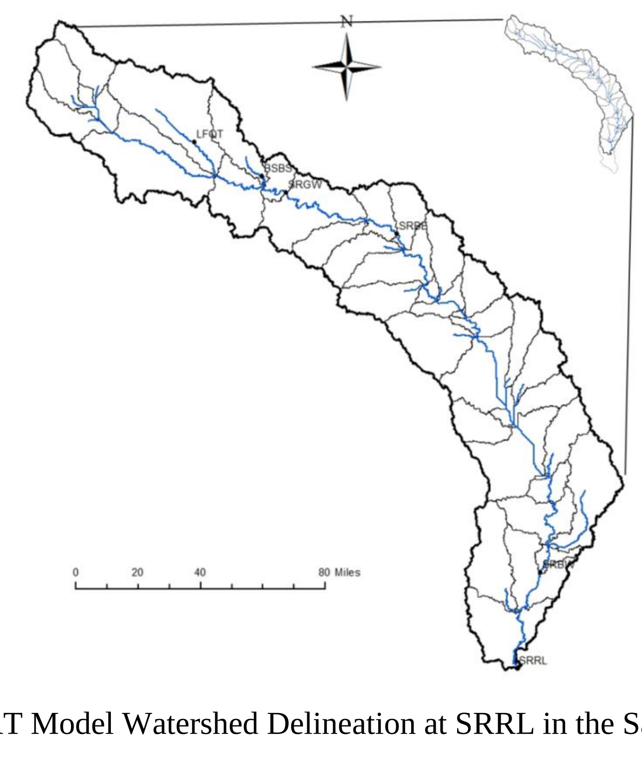



Figure 4.10 SWAT Model Watershed Delineation at SRRL in the Sabine River Basin


Figure 4.11 SWAT Model Watershed Delineation at ATCH in the Neches River Basin

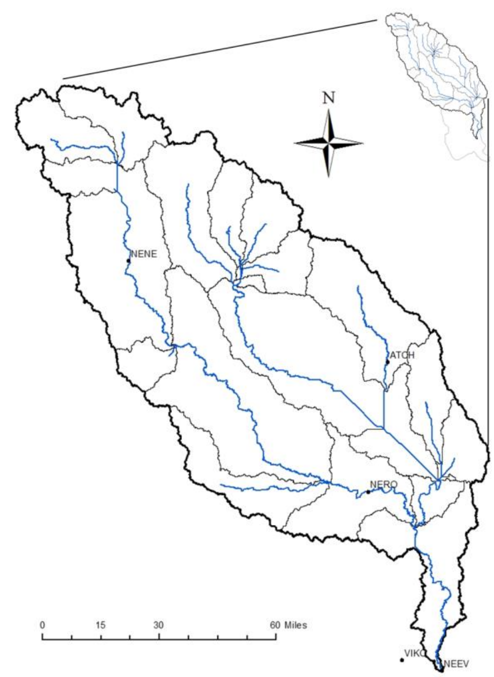



Figure 4.12 SWAT Model Watershed Delineation at NEEV in the Neches River Basin

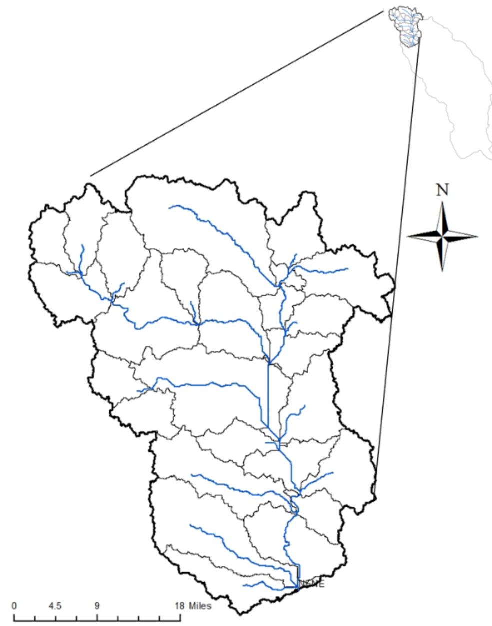



Figure 4.13 SWAT Model Watershed Delineation at NENE in the Neches River Basin


Figure 4.14 SWAT Model Watershed Delineation at NERO in the Neches River Basin

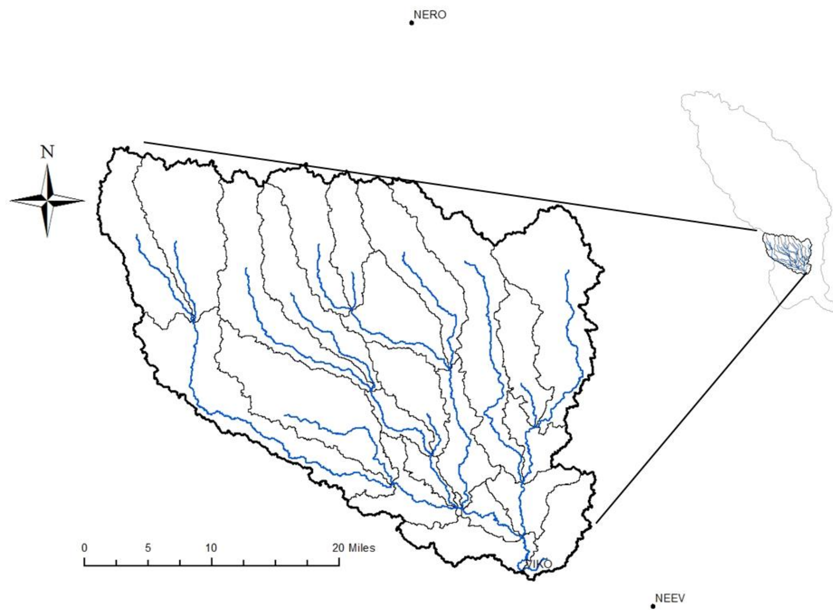



Figure 4.15 SWAT Model Watershed Delineation at VIKO in the Neches River Basin

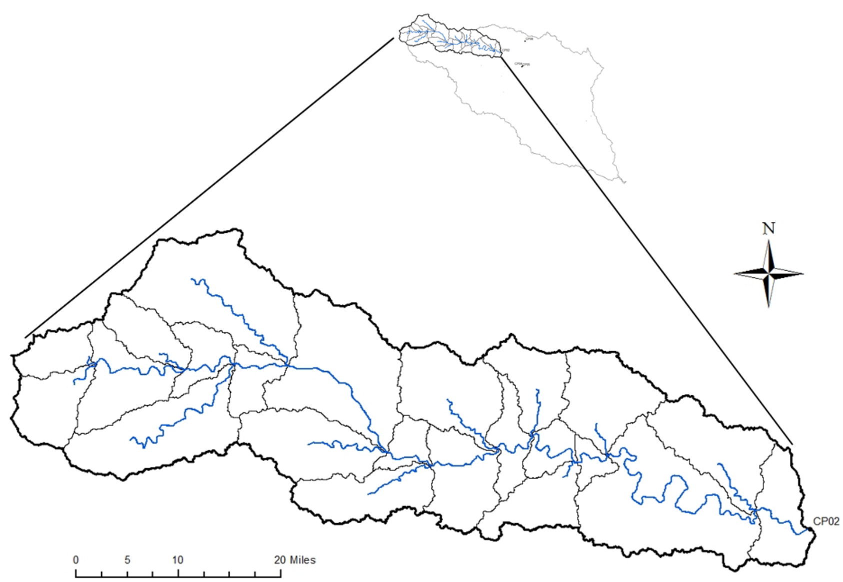



Figure 4.16 SWAT Model Watershed Delineation at CP02 in the GSA River Basins

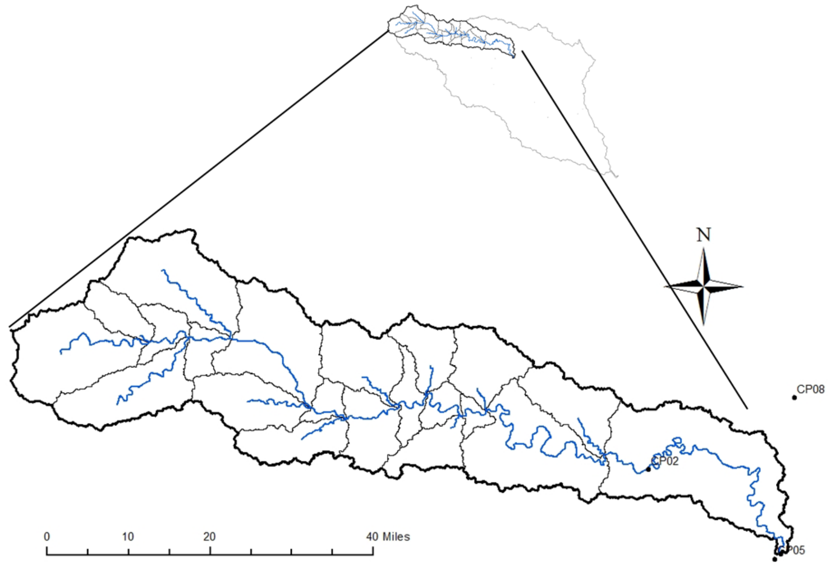



Figure 4.17 SWAT Model Watershed Delineation at CP04 in the GSA River Basins

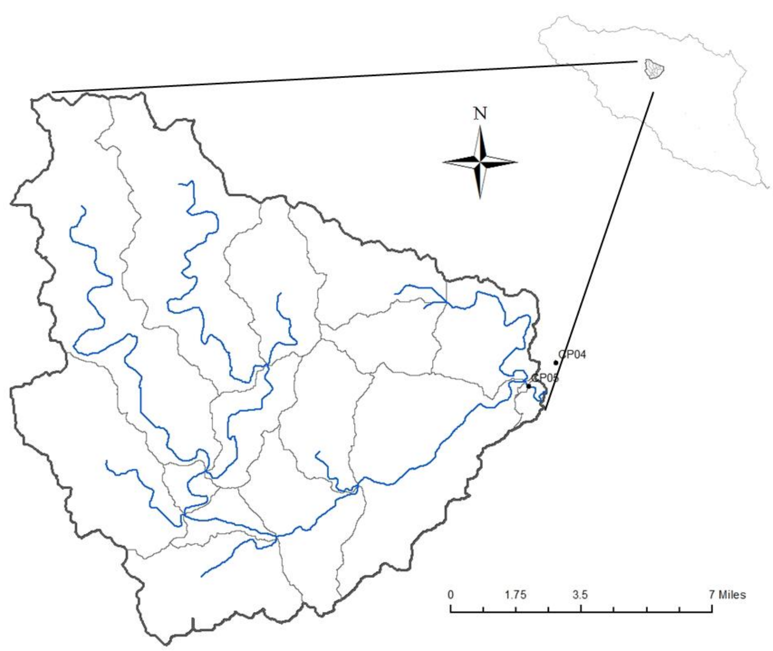



Figure 4.18 SWAT Model Watershed Delineation at CP05 in the GSA River Basins

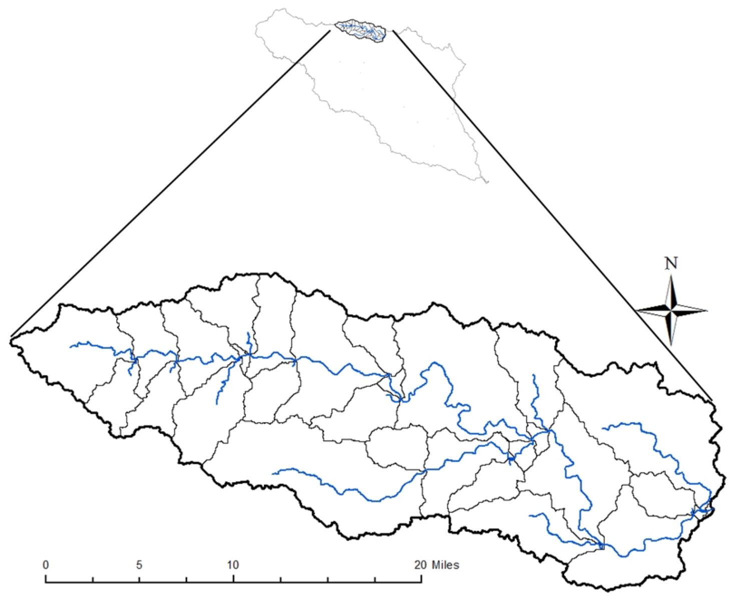



Figure 4.19 SWAT Model Watershed Delineation at CP08 in the GSA River Basins

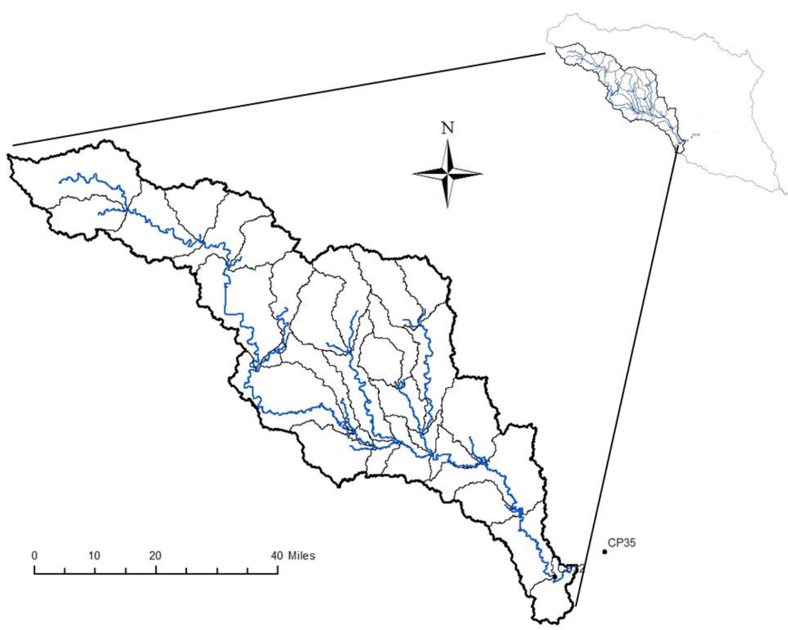



Figure 4.20 SWAT Model Watershed Delineation at CP32 in the GSA River Basins

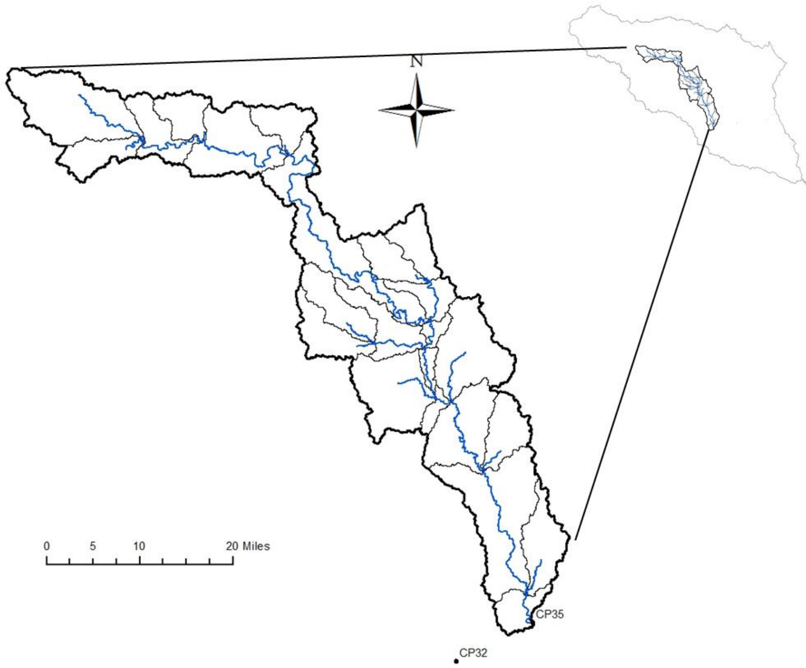



Figure 4.21 SWAT Model Watershed Delineation at CP35 in the GSA River Basins

4.3.2 Model Calibration

The recorded period and missing period are assumed for calibration of the models considering the periods-of-analysis of the three basins WAM. The periods-of-analysis are divided into warm-up, recorded and missing periods as listed in Table 4.5.

Table 4.5 Assumed Warm-up, Recorded, and Missing Periods

| Basins | Period-of-Analysis | Warm-up Period | Recorded Period | Missing Period |
|---|---|---|---|---|
| Sabine | 1940-1998 (59 yr) | 1938-1949 (10 yr) | 1950-1980 (31 yr) | 1981-1998 (18 yr) |
| Neches | 1940-1996 (57 yr) | 1938-1949 (10 yr) | 1950-1980 (31 yr) | 1981-1996 (16 yr) |
| GSA | 1934-1989 (56 yr) | 1930-1949 (20 yr) | 1950-1975 (26 yr) | 1976-1989 (14 yr) |

The parameters to be calibrated are listed in Section 2, and the calibration procedure using SWAT-CUP is as follows:

1) Determine calibrated parameters.
2) Run initial simulation and plot the simulated and recorded flow sequences.
3) Determine initial uncertainty range to each parameter within physically allowable ranges.
4) Run the SWAT-CUP 300 to 500 times and then check the result of objective function.
5) Determine again uncertainty range within physically allowable ranges according to suggested ranges by the Model.
6) Repeat the process 4 and 5 until to get maximum value of objective function.
7) Attaining the calibrated parameters and input the SWAT model.

Table 4.6 summarizes the calibration results of each SWAT model. The average $R^2$ considerably increases from 0.66 without calibration to 0.80 with calibration for the Sabine, from 0.73 to 0.87 for the Neches, and from 0.60 to 0.75 for the GSA, respectively. The $R^2$ at the control point CP05 in the GSA River Basins tremendously increases from 0.27 to 0.77 after calibration. The linear correlation relationships between monthly naturalized and synthesized flows by SWAT with and without calibration are plotted with linear regression equations and coefficients of determination ($R^2$) using Microsoft Excel as shown in Figures 4.22 to 4.38.

Table 4.6 Calibration Results of SWAT Models

| Control Points | Coefficient of Determination ($R^2$) (Naturalized vs. SWAT Flows) Without Calibration | With Calibration |
|---|---|---|
| Sabine River Basin (Calibration Period: 1950 to 1980, 31 years) | | |
| LFQT | 0.66 | 0.73 |
| BSBS | 0.64 | 0.77 |
| SRGW | 0.64 | 0.76 |
| SRBE | 0.63 | 0.83 |
| SRBW | 0.70 | 0.86 |
| SRRL | 0.71 | 0.87 |

Table 4.6 (Continued)

| Control Points | Coefficient of Determination ($R^2$) (Naturalized vs. SWAT Flows) Without Calibration | With Calibration |
|---|---|---|
| Neches River Basin (Calibration Period: 1950 to 1980, 31 years) | | |
| ATCH | 0.73 | 0.83 |
| NEEV | 0.77 | 0.91 |
| NENE | 0.68 | 0.85 |
| NERO | 0.74 | 0.90 |
| VIKO | 0.71 | 0.87 |
| GSA River Basins (Calibration Period: 1950 to 1975, 26 years) | | |
| CP02 | 0.64 | 0.73 |
| CP04 | 0.62 | 0.71 |
| CP05 | 0.27 | 0.77 |
| CP08 | 0.75 | 0.78 |
| CP32 | 0.64 | 0.70 |
| CP35 | 0.70 | 0.81 |

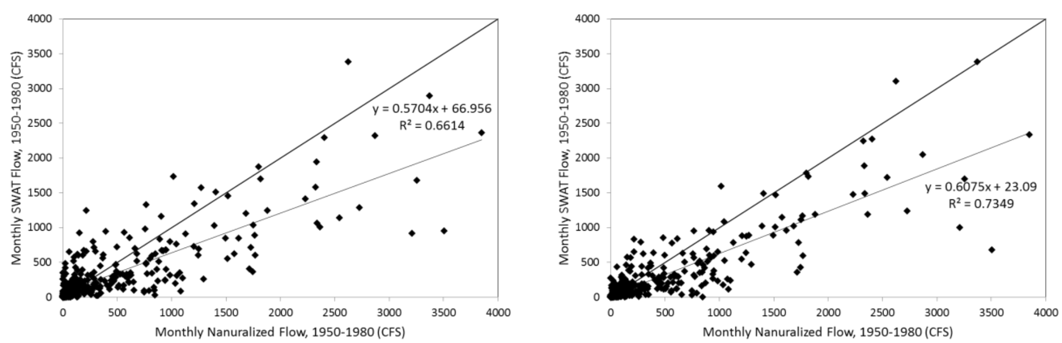



Figure 4.22 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at LFQT in the Sabine River Basin

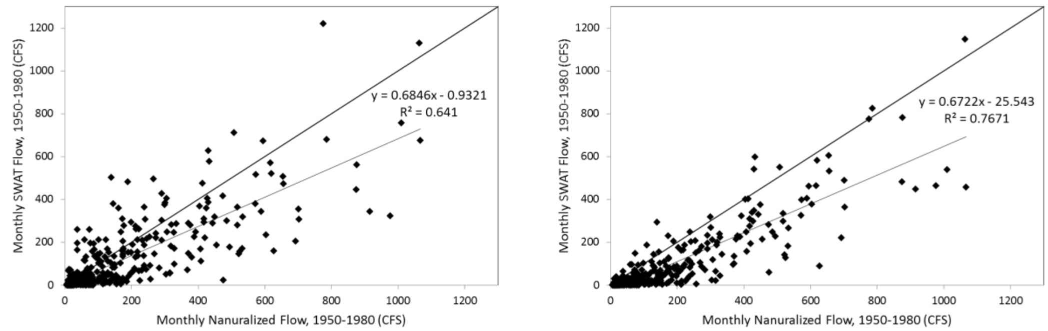



Figure 4.23 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at BSBS in the Sabine River Basin

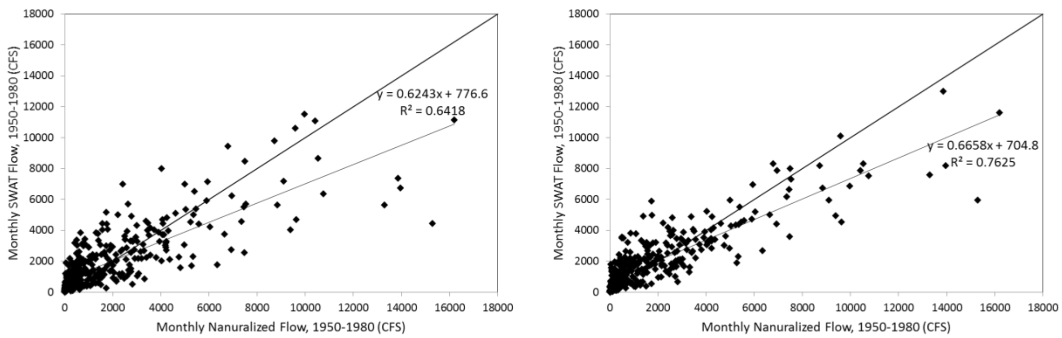



Figure 4.24 Linear Correlations between Monthly Naturalized and SWAT Flows with (below) and without (above) Calibration at SRGW in the Sabine River Basin

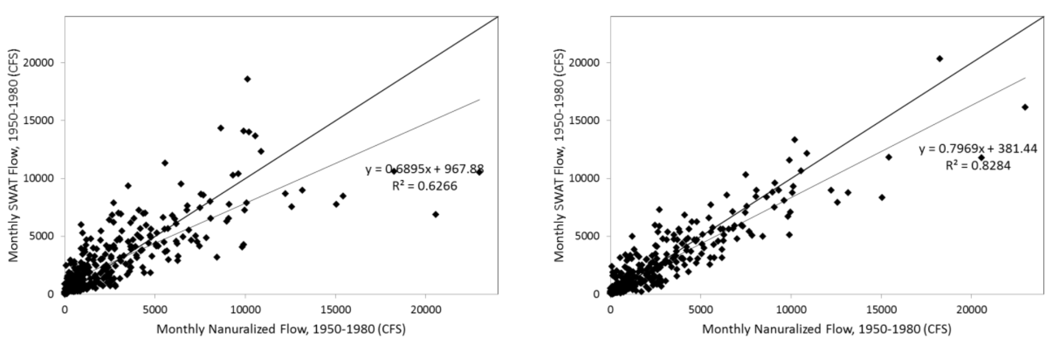



Figure 4.25 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at SRBE in the Sabine River Basin

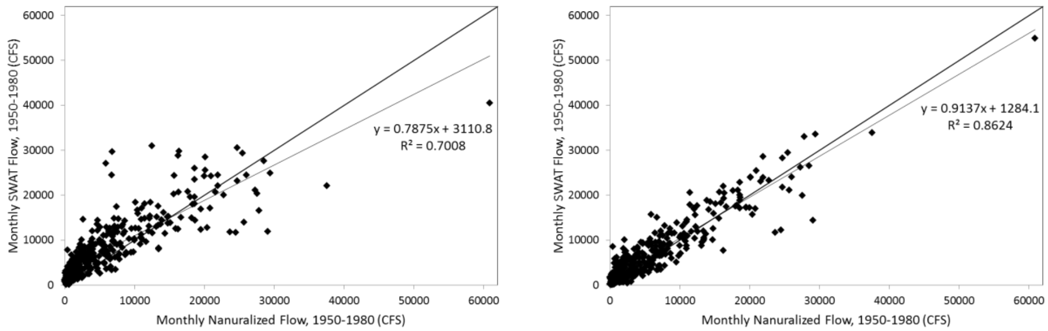



Figure 4.26 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at SRBW in the Sabine River Basin

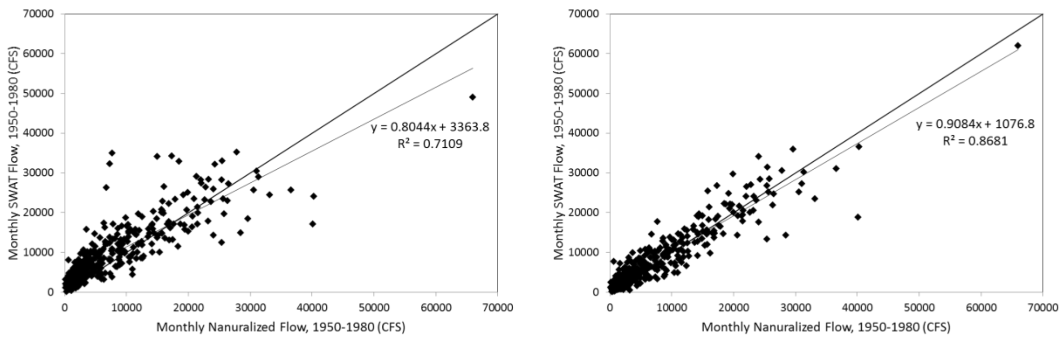



Figure 4.27 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at SRRL in the Sabine River Basin

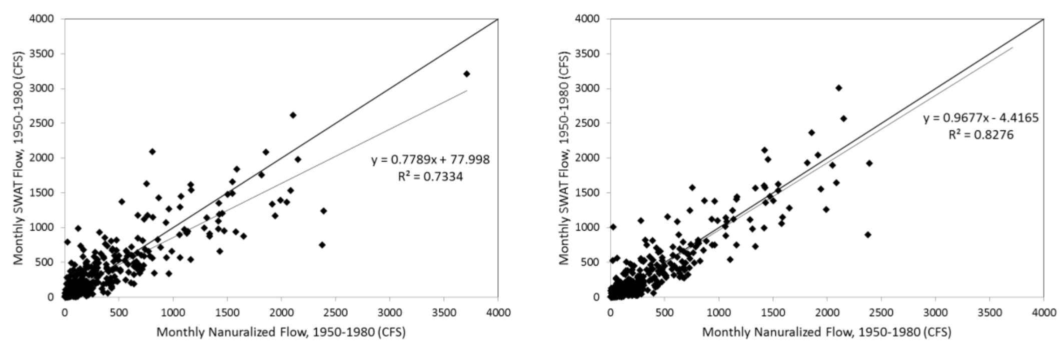



Figure 4.28 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at ATCH in the Neches River Basin

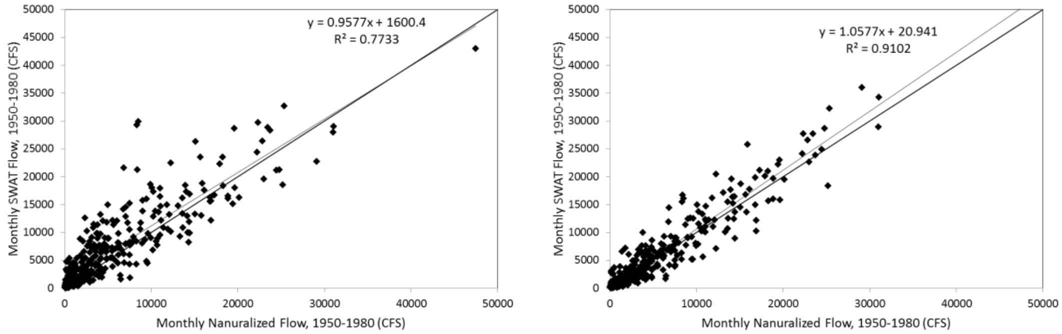



Figure 4.29 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at NEEV in the Neches River Basin

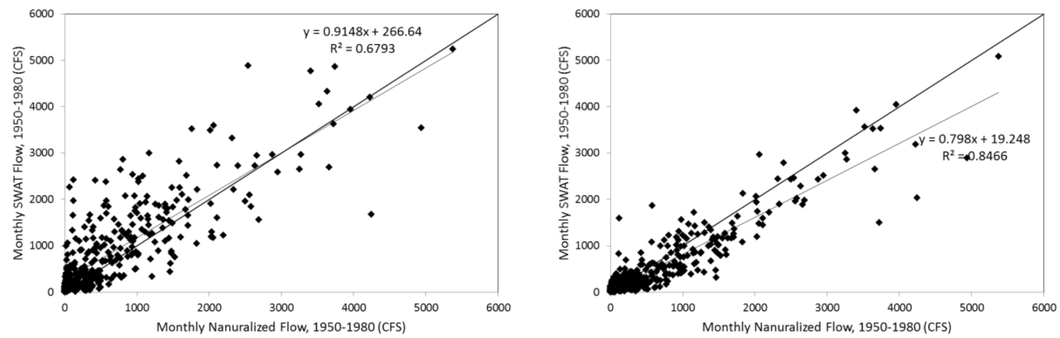



Figure 4.30 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at NENE in the Neches River Basin

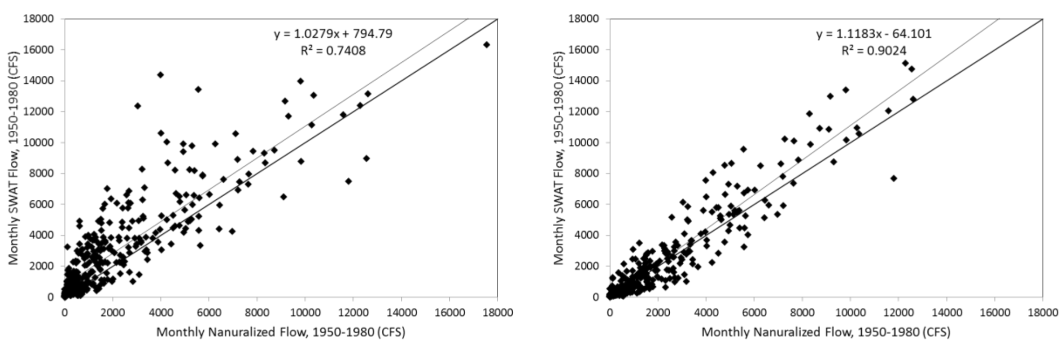



Figure 4.31 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at NERO in the Neches River Basin

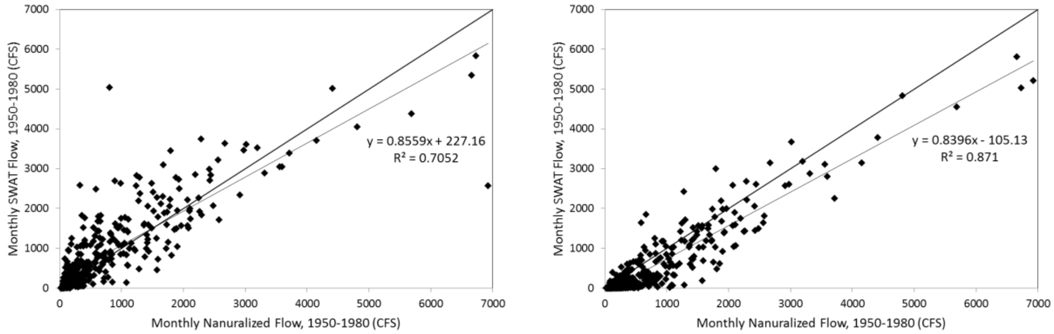



Figure 4.32 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at VIKO in the Neches River Basin

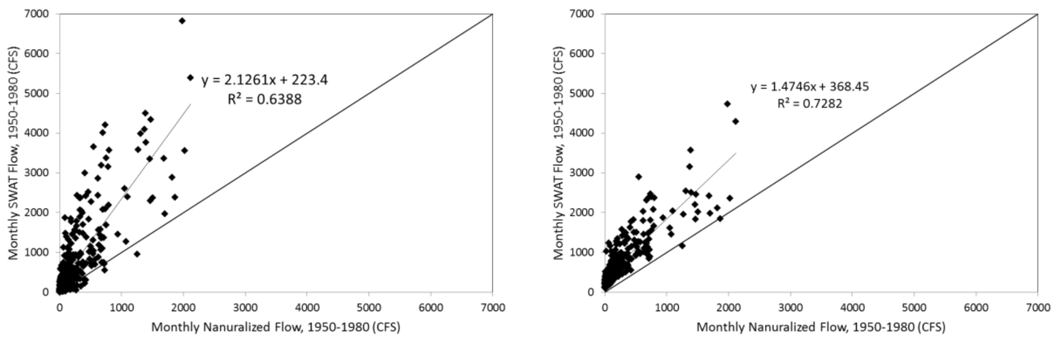



Figure 4.33 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP02 in the GSA River Basins

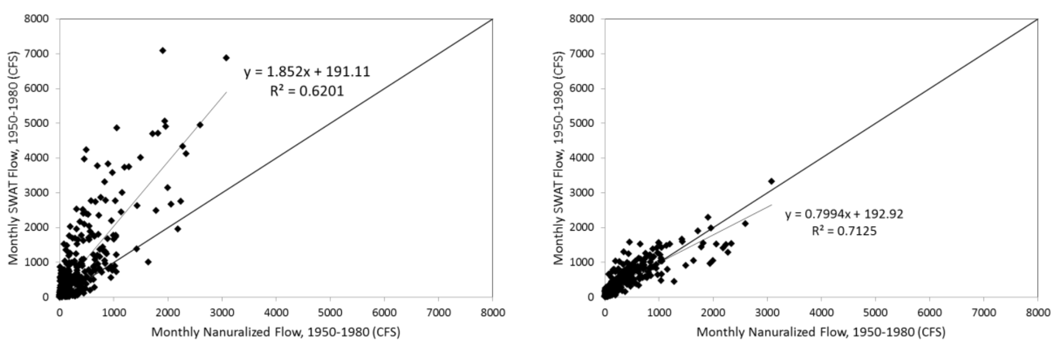



Figure 4.34 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP04 in the GSA River Basins

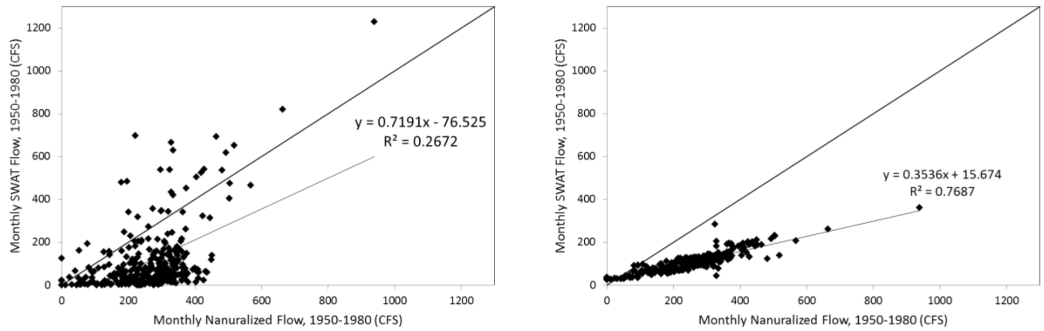



Figure 4.35 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP05 in the GSA River Basins

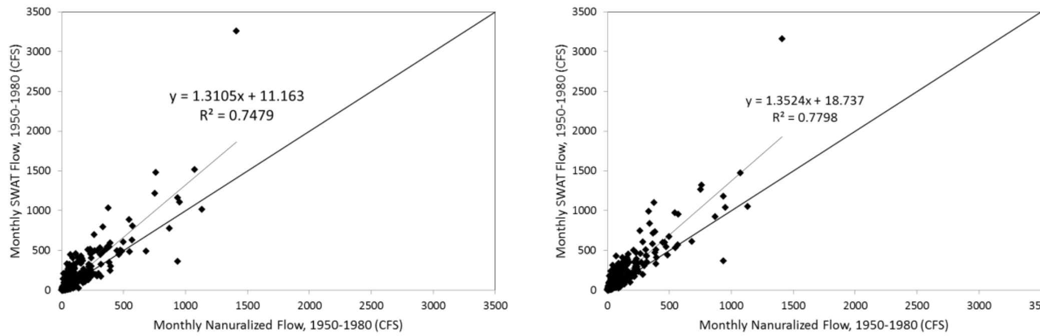



Figure 4.36 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP08 in the GSA River Basins

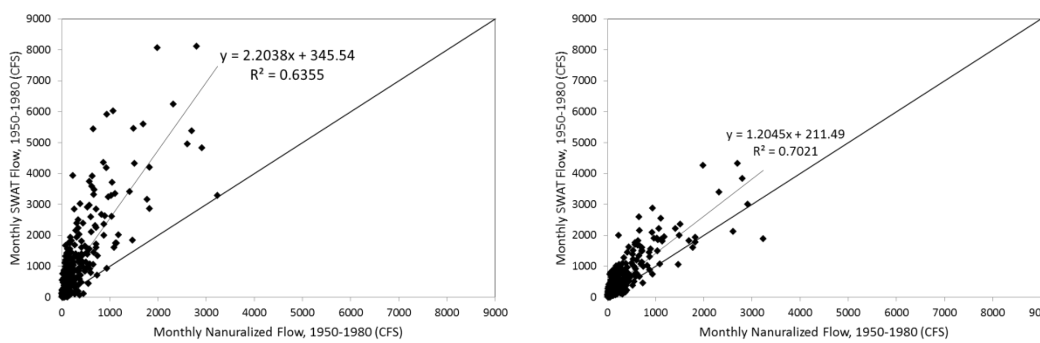



Figure 4.37 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP32 in the GSA River Basins

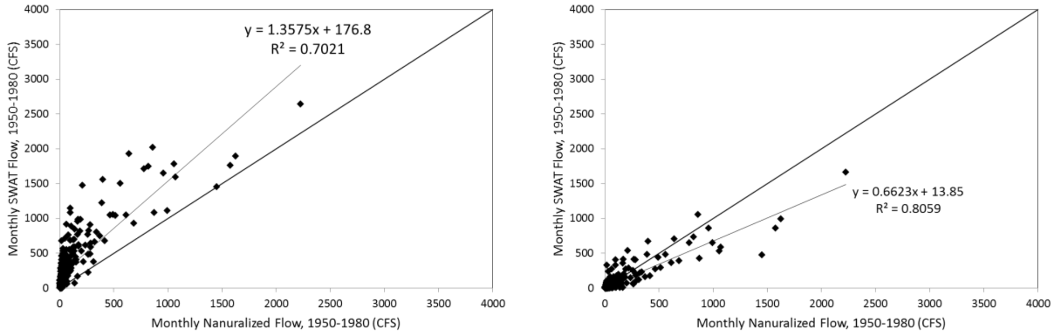



Figure 4.38 Linear Correlations between Monthly Naturalized and SWAT Flows with (right) and without (left) Calibration at CP35 in the GSA River Basins

4.4 Filling in Gaps of Missing Data with MOVE2

MOVE2 consists of two processes: (1) estimating unbiased mean and variance and (2) transferring flow sequences at a source site to a target site on the basis of estimated unbiased mean and variance. This method is expected to keep the homogeneity of flow sequences at a target site by this complexity process to estimate the unbiased mean and variance. Linear transfer methods generally tend to alter statistical characteristics of flow sequences at a target site, when filling in gaps of its missing period based on a source site.

Unbiased means and variances, called “population means and variances”, of flow sequences including the missing period at each control point for the three WAMs are calculated by Equation 2.2, 2.3, and 2.4 based on synthetic flow sequences by each SWAT model. Equation 2.2 estimates population means with linear correlation coefficient between two flow sequences for the recorded periods, numbers of data, and each mean and variance for recorded period. Equation 2.3 estimates population variances with various variables like equation 2.3 and noises by equation 2.4. Table 4.7 summarizes unbiased means and variance of flow sequences at control points in the Sabine, the Neches, and the GSA River basins, respectively.

Equation 2.1 transfers the flows sequences for filling gaps of missing data on the basis of synthesized flow sequences by SWAT. Equation 2.1 may generate negative values if the difference between flow value and mean is bigger than the estimated mean. If negative values are generated in transferring flow values, the negative values are replaced with zero flow.

Table 4.7 Unbiased Means and Variances at Control Points in the Sabine River Basin

| Control Points | Product Moment Correlation Coefficient (NF vs. SWAT) | Alpha (α) | Estimated Unbiased (1950-1998) | | WAM Datasets (1950-1998) | |
|---|---|---|---|---|---|---|
| | | | Mean m(y) (CFS) | Variance S(y) (CFS) | Mean m'(y) (CFS) | Variance S'(y) (CFS) |
| Sabine | | | | | | |
| LFQT | 0.86 | 1.00 | 517.5 | 715.5 | 459.9 | 661.2 |
| BSBS | 0.88 | 1.00 | 175.6 | 193.1 | 181.5 | 201.1 |
| SRGW | 0.87 | 1.00 | 2,080.4 | 2,582.7 | 2,062.5 | 2,617.6 |
| SRBE | 0.91 | 1.00 | 2,895.2 | 3,246.0 | 2,454.9 | 3,246.1 |
| SRBW | 0.93 | 1.00 | 7,285.0 | 7,748.1 | 7,062.8 | 7,734.2 |
| SRRL | 0.93 | 1.00 | 8,982.7 | 8,653.1 | 8,453.2 | 8,525.2 |
| Neches | | | | | | |
| ATCH | 0.91 | 1.01 | 446.5 | 528.9 | 435.8 | 542.4 |
| NEEV | 0.95 | 1.01 | 6,551.5 | 6,782.3 | 5,926.3 | 6,743.4 |
| NENE | 0.92 | 1.01 | 829.8 | 974.0 | 794.2 | 887.9 |
| NERO | 0.95 | 1.01 | 2,458.0 | 2,670.4 | 2,270.9 | 2,789.8 |
| VIKO | 0.93 | 1.01 | 817.9 | 1,023.6 | 845.7 | 1,021.0 |
| GSA | | | | | | |
| CP02 | 0.87 | 1.01 | 339.4 | 429.3 | 365.7 | 550.4 |
| CP04 | 0.85 | 1.01 | 473.2 | 568.1 | 479.1 | 626.0 |
| CP05 | 0.87 | 1.01 | 292.0 | 105.0 | 276.3 | 109.0 |
| CP08 | 0.89 | 1.01 | 134.4 | 188.5 | 137.4 | 201.7 |
| CP32 | 0.85 | 1.01 | 380.0 | 494.7 | 422.7 | 660.6 |
| CP35 | 0.90 | 1.01 | 122.1 | 272.5 | 113.9 | 260.1 |

## 4.5 Comparative Analysis

### 4.5.1 Statistical Evaluation

The method performance is evaluated with two different statistical methods: the Nash-Sutcliffe efficiency (NSE) and comparison of statistic parameters. NSE is a normalized statistic to be determined by comparing the relative magnitude of the residual variance (“noise) to the measured or recorded data variance (“information”) (Nash and Sutcliffe, 1970). NSE ranges from $-\infty$ to 1.0. If the NSE value is 1.0, that means the optimal values. NSE values between 0.0 and 1.0 are generally considered acceptable levels of performance while values of less than 0.0 indicate unacceptable performance. Moriasi *et al.* (2007) suggested that if NSE is more than 0.5, model performance can be evaluated as “satisfactory” through a thorough review of relevant literature.

Table 4.8 summarizes the performances at each control point with NSE values with and without MOVE2. The flow sequences synthesized with the calibrated SWAT models (the source flows) have NSE values ranging from -3.03 to 0.85, and the flow sequences (the infilled flows) transferred by MOVE2 based on the synthesized flow sequences by the calibrated SWAT models have a range of NSE values from 0.48 to 0.86 with the naturalized flow data for the assumed missing period at all 17 control points.

Table 4.9 also summarizes the statistical parameters of the flow sequences for missing periods at each control point for the Sabine, the Neches, and the GSA River Basins. This shows that the statistical parameters (mean and variance) of the infilled flows are closer to the parameters of the flow sequences of WAM datasets than sources for missing periods at 11 out of 17 control points.

In further detail for each basin, the infilled flows have satisfied NSE values with the naturalized flow data at the six control points in the Sabine River basin. MOVE2 makes the source flows close to the naturalized flow data at the control point BSBS, while this method spoils NSE value from 0.71 to 0.56, even satisfied, at the control point LFQT. However, MOVE2 shows obviously satisfied performances at all the 6 control points.

Table 4.8 Summary of Method Performance Evaluation by Nash-Sutcliffe Efficiency

| Control Points | Nash-Sutcliffe Efficiency (NSE) (Naturalized vs. Infilled flows) SWAT Flow Only | MOVE2 Based SWAT Flow |
|---|---|---|
| Sabine River Basin (Missing Period: 1981 to 1998, 18 years) | | |
| LFQT | 0.71 | 0.56 |
| BSBS | 0.44 | 0.73 |
| SRGW | 0.70 | 0.71 |
| SRBE | 0.83 | 0.83 |
| SRBW | 0.85 | 0.85 |
| SRRL | 0.85 | 0.85 |
| Neches River Basin (Missing Period: 1981 to 1996, 16 years) | | |
| ATCH | 0.78 | 0.79 |
| NEEV | 0.82 | 0.86 |
| NENE | 0.78 | 0.64 |
| NERO | 0.84 | 0.86 |
| VIKO | 0.52 | 0.61 |
| GSA River Basins (Missing Period: 1976 to 1989, 14 years) | | |
| CP02 | 0.38 | 0.77 |
| CP04 | 0.72 | 0.73 |
| CP05 | -3.03 | 0.48 |
| CP08 | 0.68 | 0.83 |
| CP32 | 0.63 | 0.57 |
| CP35 | 0.70 | 0.61 |

The infilled flows have satisfied NSE values with the naturalized flow data at the five control points in the Neches River basin. MOVE2 generally improves NSE values at all control points, while NSE value decreases from 0.78 to 0.64 at the control point NENE after infilling with MOVE2. However, it is also made within the level of satisfactory like the control point LFQT in the Sabine River Basin.

The NSE values increase at the control points CP02, CP04, CP05, and CP08, and slightly decrease at the control points CP32 and CP35 after infilling by MOVE2 in the

GSA River Basins. MOVE2 makes the flow characteristics tremendously close to the naturalized flow data at the control points CP02 and CP05. MOVE2 enhances NSE values from 0.38 to 0.77 for the control point CP02, and NSE values from -3.03 to 0.48 for the control point CP05, respectively.

Table 4.9 Statistical Parameters of the Flow Sequences for Missing Periods

| Control Points | Infilled Flows by MOVE2 (1981-1998) | | WAM Dataset (1981-1998) | | Sources(SWAT) Flows (1981-1998) | |
|---|---|---|---|---|---|---|
| | Mean m(y) (CFS) | Variance S(y) (CFS) | Mean m'(y) (CFS) | Variance S'(y) (CFS) | Mean m"(y) (CFS) | Variance S"(y) (CFS) |
| Sabine | | | | | | |
| LFQT | 669.1 | 808.3 | 542.9 | 659.8 | 447.7 | 588.5 |
| BSBS | 183.1 | 182.9 | 203.8 | 205.9 | 96.8 | 139.4 |
| SRGW | 2,350.1 | 2,444.7 | 2,348.5 | 2,612.6 | 2,211.1 | 1,909.9 |
| SRBE | 3,322.0 | 3,179.8 | 3,199.0 | 3,181.3 | 2,961.5 | 2,781.7 |
| SRBW | 8,443.3 | 8,332.6 | 8,313.7 | 8,192.9 | 8,884.1 | 8,263.4 |
| SRRL | 10,281.8 | 9,104.6 | 9,451.6 | 8,759.4 | 10,241.5 | 8,923.6 |
| Neches | | | | | | |
| ATCH | 525.5 | 582.2 | 535.1 | 604.8 | 496.7 | 626.1 |
| NEEV | 7,938.2 | 7,165.4 | 7,039.3 | 7,083.3 | 8,022.2 | 7,976.3 |
| NENE | 1,004.2 | 1,119.8 | 794.2 | 887.9 | 812.3 | 985.5 |
| NERO | 2,924.1 | 2,711.8 | 2,738.8 | 3,037.0 | 3,038.7 | 3,198.1 |
| VIKO | 875.3 | 1,058.0 | 998.5 | 1,031.5 | 617.2 | 953.9 |
| GSA | | | | | | |
| CP02 | 408.2 | 494.6 | 511.4 | 743.0 | 985.2 | 884.0 |
| CP04 | 593.7 | 677.1 | 631.4 | 793.0 | 691.2 | 673.9 |
| CP05 | 342.2 | 82.8 | 309.2 | 99.6 | 126.2 | 32.6 |
| CP08 | 144.0 | 180.6 | 161.2 | 219.0 | 212.3 | 275.3 |
| CP32 | 421.9 | 499.1 | 576.5 | 865.2 | 718.9 | 723.2 |
| CP35 | 131.2 | 302.9 | 114.5 | 265.8 | 100.5 | 227.0 |

Linear correlation with a regression equation can intuitionally demonstrate how much or well MOVE2 changes the statistic parameters of the source flows similar to the statistic parameters of the naturalized flow data. A linear regression equation without intercept can be expressed as Y=BX. B is a slope of relationship between A and B. If the statistic characteristics of Ys are almost similar to Xs, the slope should be 1. Therefore, a slope of a linear regression equation without intercept represents statistic similarity of both time series. The linear relationships between naturalized flows and the source flow and the infilled flow at all control points are as shown in Figures 4.39 to 4.55.

In the Sabine River Basin, Figure 4.40 especially shows that MOVE2 changes the flow characteristics of the source flow close to the characteristics of the naturalized flow data. However, if the sources flows are originally developed close to the naturalized flow data like the control points SRBW and SRRL, the modification by MOVE2 is marginal as shown in Figures 4.43 and 4.44.

Flow characteristics of the infilled flows are slighted adjusted to the naturalized flows at all the control points in the Neches River Basin as shown in Figures 4.45 to 4.48. This is because the source flows are well developed in general. However, if there some difference between the source flow and the naturalized flow like at the control point VIKO, MOVE2 also adjust flow characteristics of the source flow similar to the naturalized flow as shown in Figure 4.49.

In the GSA River Basins, the improvement of flow characteristics by MOVE2 is more obvious than other two river basins as shown in Figures 4.50 to 4.55. The source flow has totally different flow characteristics than the naturalized flow at the control point CP05 due to a spring flow source within its watershed. However, MOVE2 surprisingly changes the characteristics of the source flow similar to the naturalized flow at the control point CP05 as shown in Figure 4.53, if both flows have highly linear correlation. Even though, this regression equation intuitionally shows the alteration of flow characteristics, it sometimes could provide wrong information due to over or under estimated maximum values as shown in Figures 4.50 and 4.54. These two figures shows that MOVE2 spoils flow characteristics of the sources flows at CP02 and CP32, but Table 4.9 indicates that this method really changes overestimated means of the sources flows close to the means of the naturalized flows at the two control points. This problem can be addressed by the flow frequency analysis in the next section.

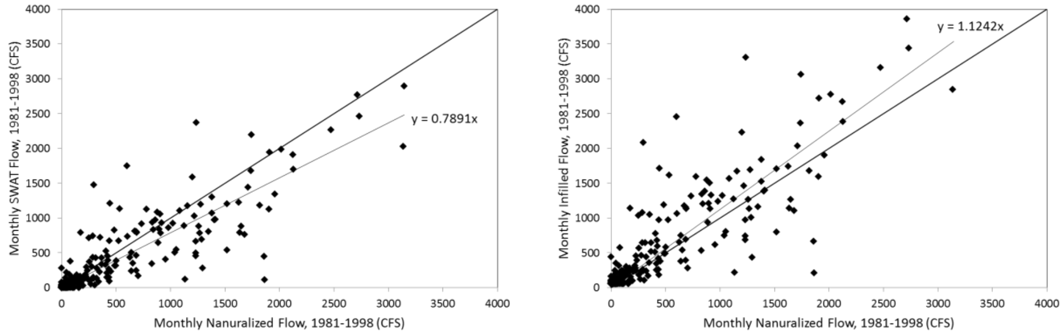



Figure 4.39 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at LFQT in the Sabine River Basin

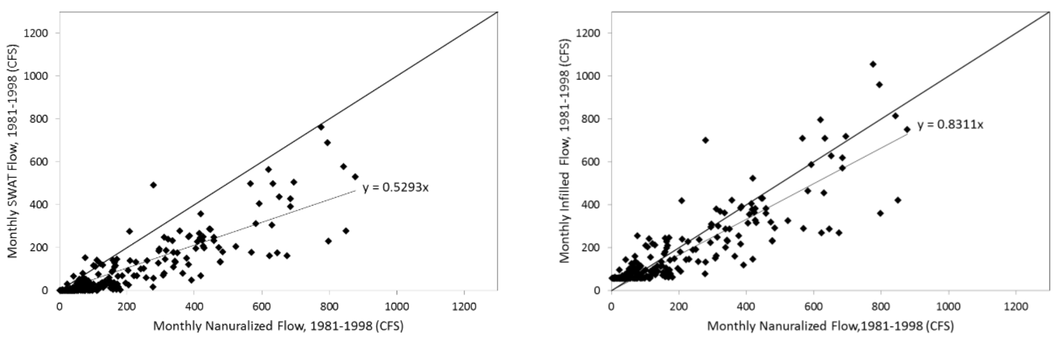



Figure 4.40 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at BSBS in the Sabine River Basin

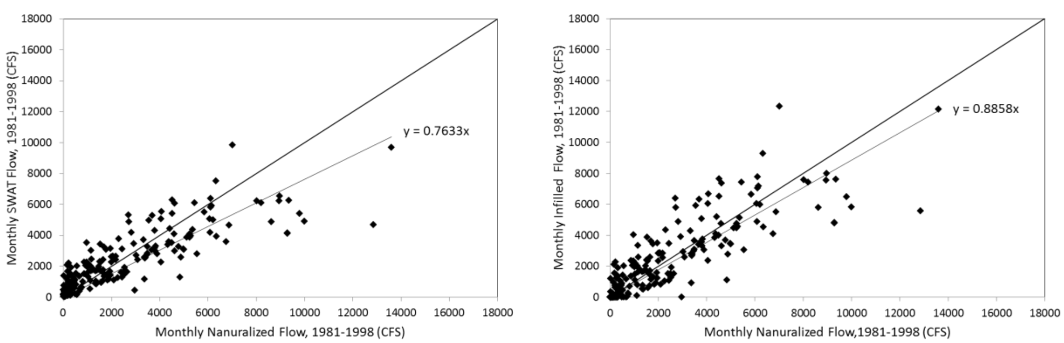



Figure 4.41 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at SRGW in the Sabine River Basin

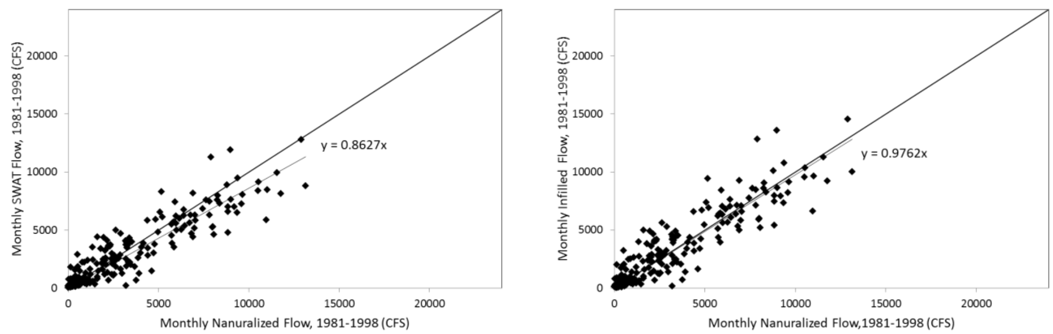



Figure 4.42 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at SRBE in the Sabine River Basin

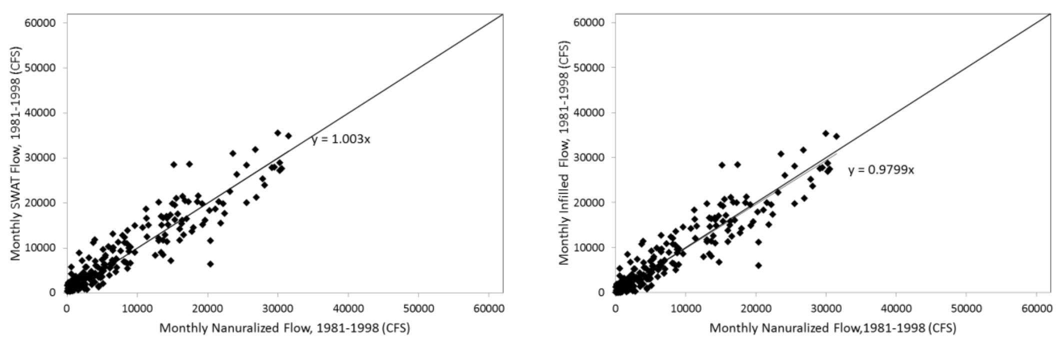



Figure 4.43 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at SRBW in the Sabine River Basin

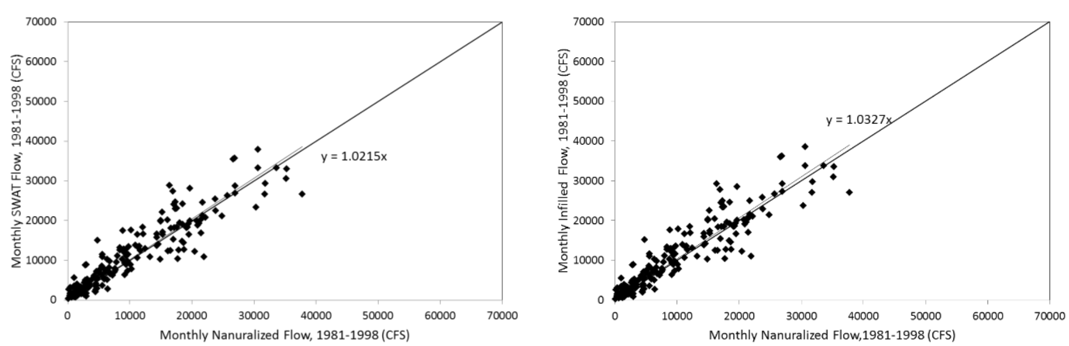



Figure 4.44 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at SRRL in the Sabine River Basin

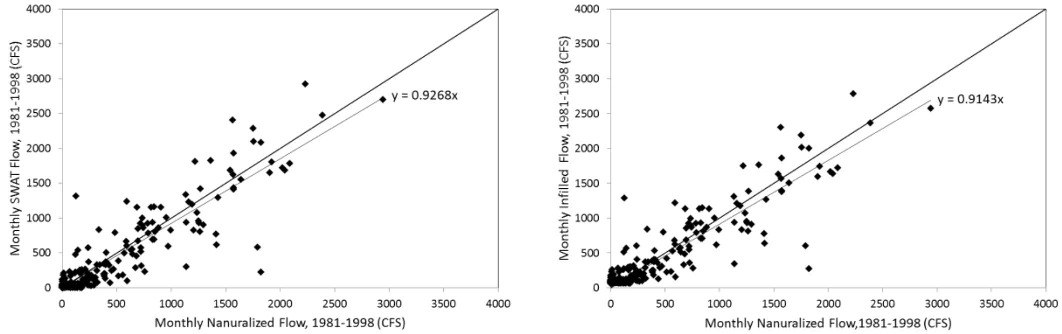



Figure 4.45 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at ATCH in the Neches River Basin

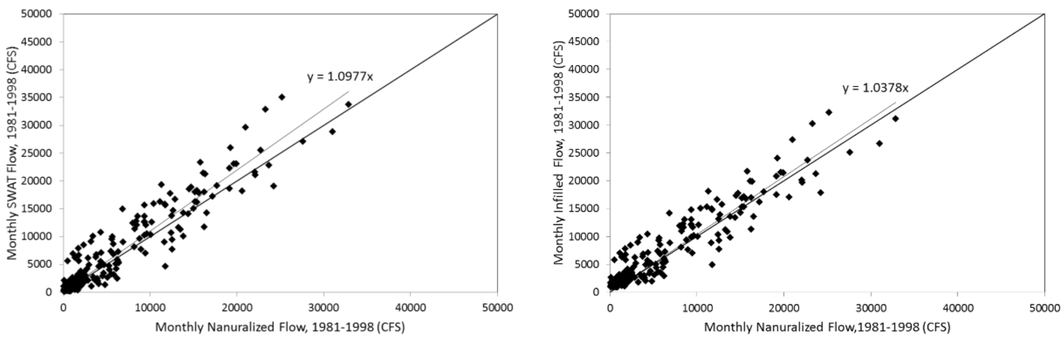



Figure 4.46 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at NEEV in the Neches River Basin

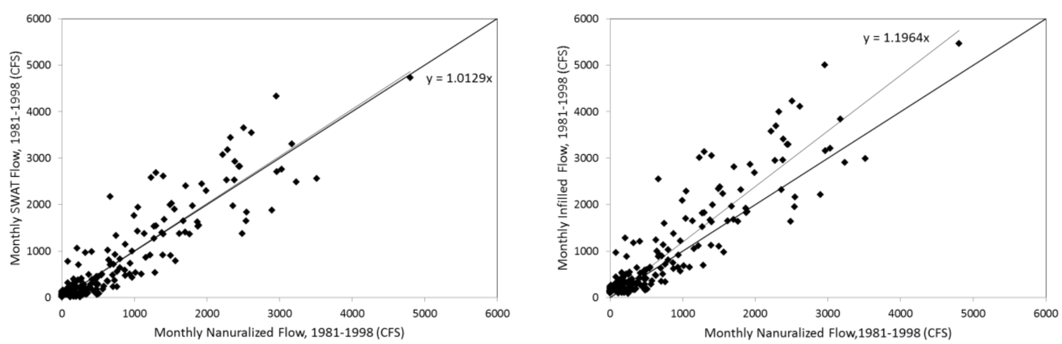



Figure 4.47 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at NENE in the Neches River Basin

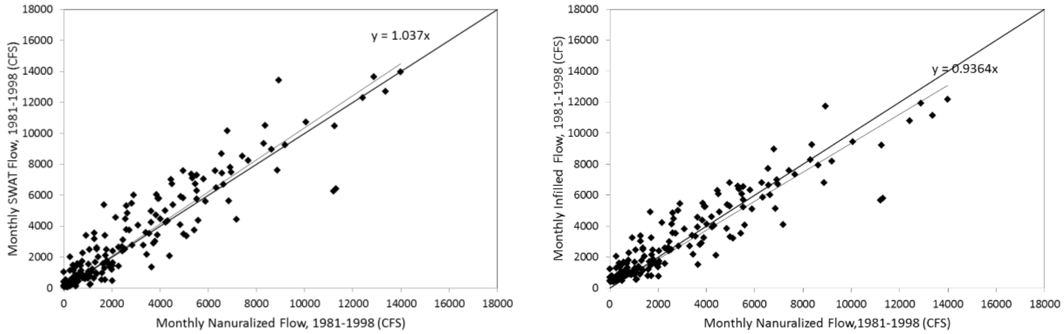



Figure 4.48 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at NERO in the Neches River Basin

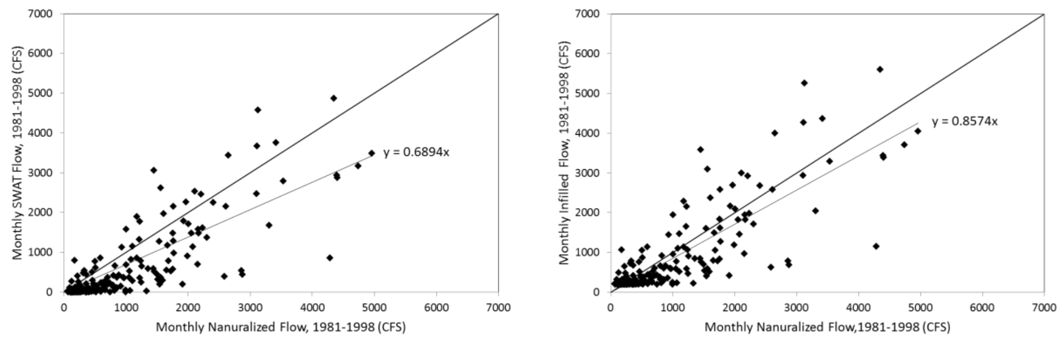



Figure 4.49 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at VIKO in the Neches River Basin

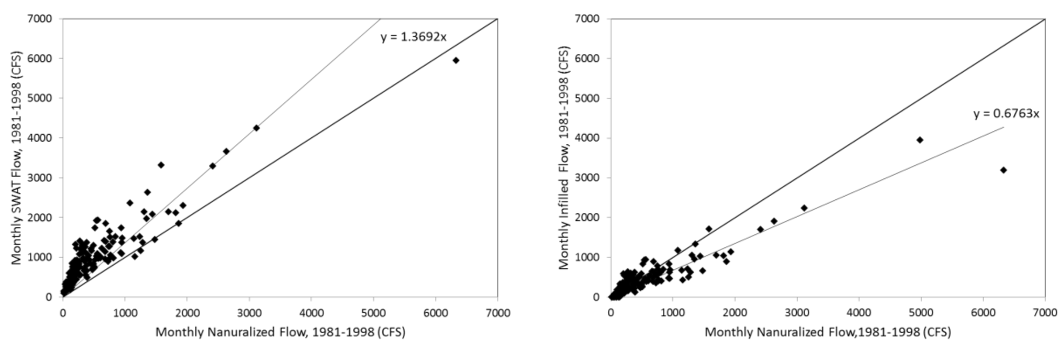



Figure 4.50 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP02 in the GSA River Basins

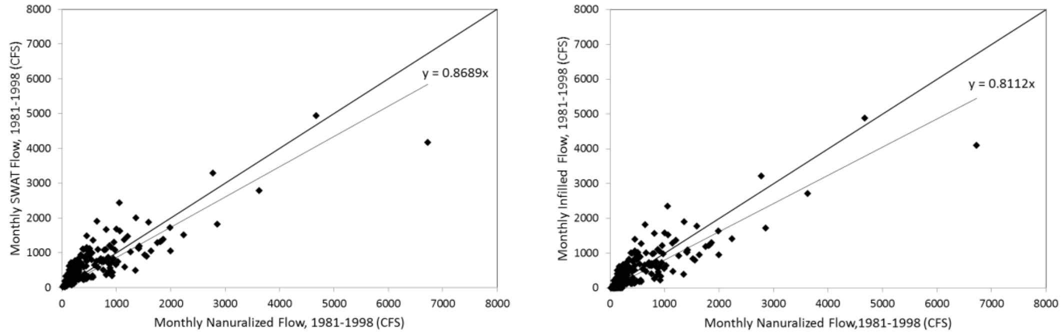



Figure 4.51 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP04 in the GSA River Basins

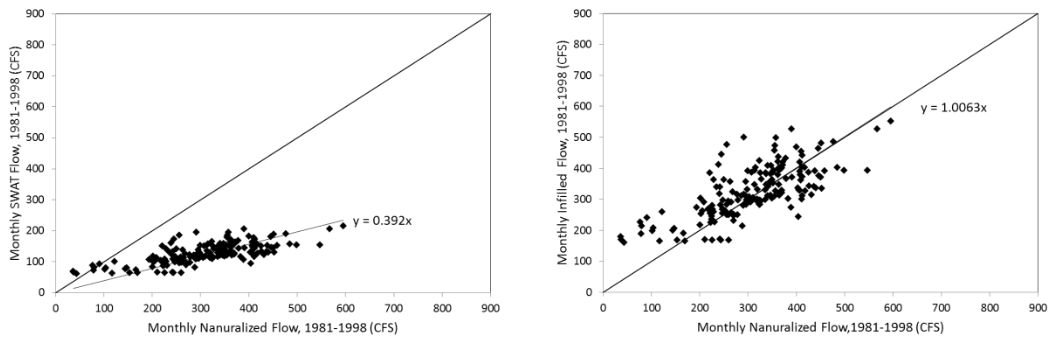



Figure 4.52 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP05 in the GSA River Basins

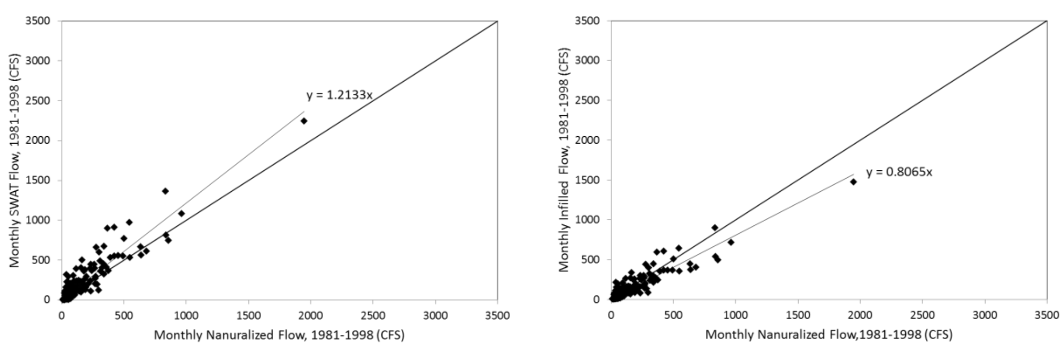



Figure 4.53 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP08 in the GSA River Basins

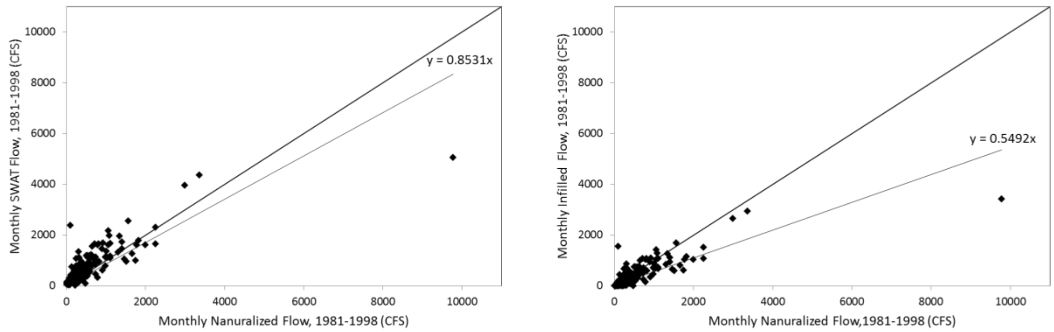



Figure 4.54 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP32 in the GSA River Basins

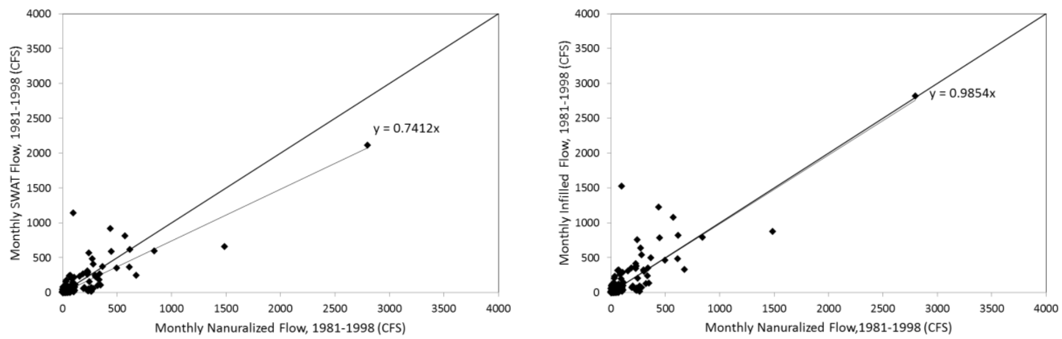



Figure 4.55 Regression Equations between Monthly Naturalized and Infilled Flows with (right) and without (left) MOVE2 at CP35 in the GSA River Basins

### 4.5.2 Comparison of Flow Frequencies

A method for filling gaps of missing data should conserve not only statistical stationarity but also flow characteristics. Flow duration curves and flow frequency metrics are widely used for evaluation of flow characteristics. Flow duration curves commonly provide a graphical illustration of the overall hydrologic state of flow sequences (Vogel et al, 2007).

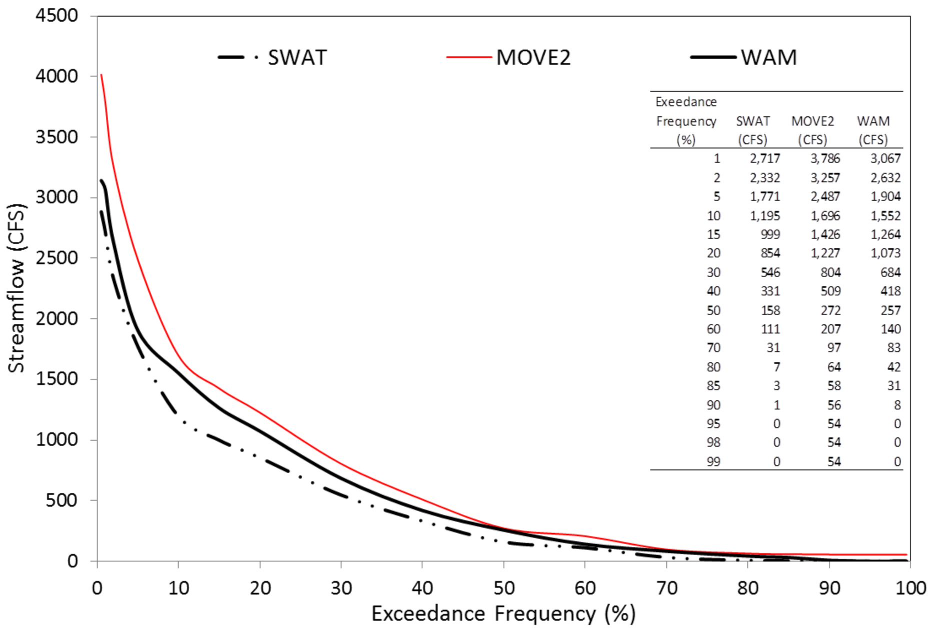
Flow duration curves of naturalized flow, the source flow, and the infilled flow at each control point for assumed missing periods are plotted in Figures 4.56 to 4.72. These figures indicate that the infilled flows at most control points are more similar to flow characteristics of naturalized flow than the source flows.

The flow frequencies of the infilled flows are very similar to the flow frequencies of the naturalized flow data for the assumed missing period at all the six primary control points in the Sabine River Basin. MOVE2 adjusts the flow frequency relationships similar to the naturalized flows at the control points LFQT, BSBS, SRGW, and SRBE, relative upstream area, than control points SRBW and SRRL, relative downstream area.

The flow frequencies of the infilled flows are also very close to the flow frequencies of the naturalized flow data for the assumed missing period at all the five primary control points in the Neches River Basin. Flow frequency of the source flow is also changed similar to the naturalized flows at the control point VIKO by MOVE2 like other evaluation methods.

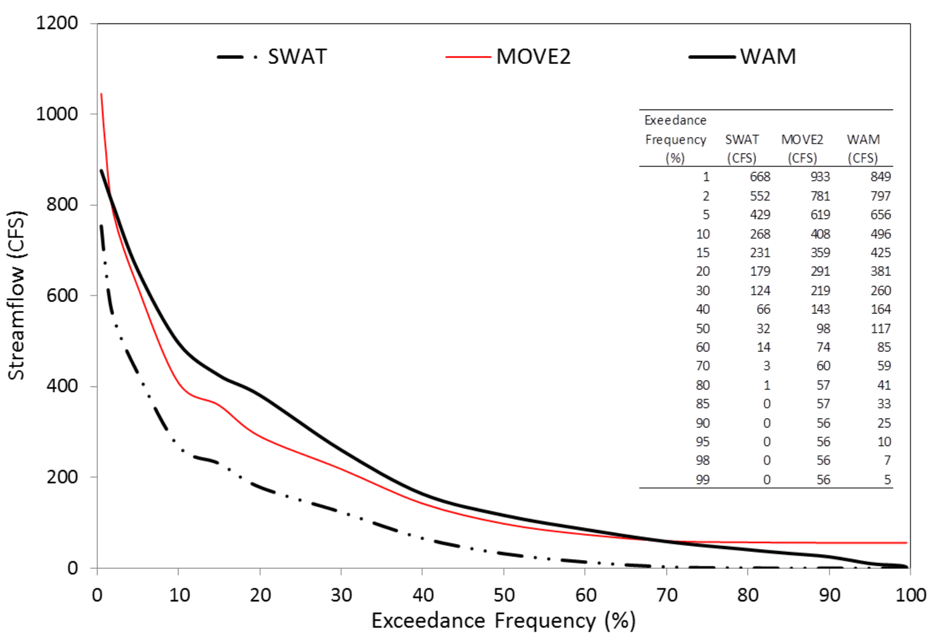
The flow frequencies of the infilled flows are very similar to the flow frequencies of the naturalized flow data for the assumed missing period at all the six primary control points in the GSA River Basins. It is more apparently that MOVE2 modifies the flow frequency similar to the naturalized flows at the control points CP02, CP05, CP08, and CP32. The flow frequency of the source flow is totally different from the naturalized flow at the control point CP05. MOVE2 dramatically changes the flow frequency nearly similar to the naturalized flow at the control point CP05. Although it could be evaluated that flow characteristics of the infilled flows are different from the naturalized flows at CP02 and CP32 through the regression equations between both flows, this flow frequency analysis proves that the infilled flows at the two points have similar flow characteristics to the naturalized flows.

These evaluations show that the suggested method is a good solution for infilling gaps of missing data, if there is no linear correlated data at near sites.



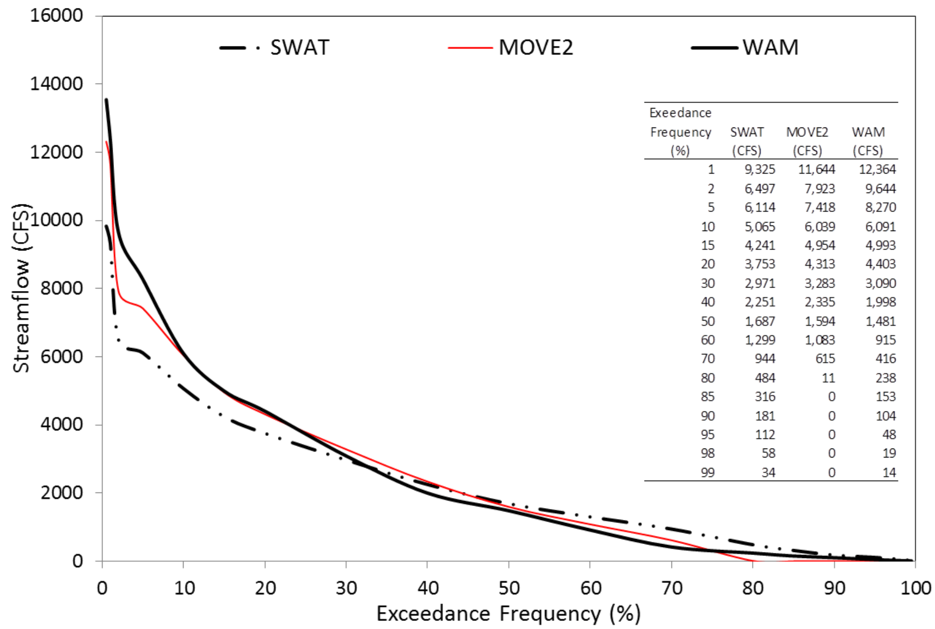

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 2,717 | 3,786 | 3,067 |
| 2 | 2,332 | 3,257 | 2,632 |
| 5 | 1,771 | 2,487 | 1,904 |
| 10 | 1,195 | 1,696 | 1,552 |
| 15 | 999 | 1,426 | 1,264 |
| 20 | 854 | 1,227 | 1,073 |
| 30 | 546 | 804 | 684 |
| 40 | 331 | 509 | 418 |
| 50 | 158 | 272 | 257 |
| 60 | 111 | 207 | 140 |
| 70 | 31 | 97 | 83 |
| 80 | 7 | 64 | 42 |
| 85 | 3 | 58 | 31 |
| 90 | 1 | 56 | 8 |
| 95 | 0 | 54 | 0 |
| 98 | 0 | 54 | 0 |
| 99 | 0 | 54 | 0 |

Figure 4.56 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at LFQT in the Sabine River Basin



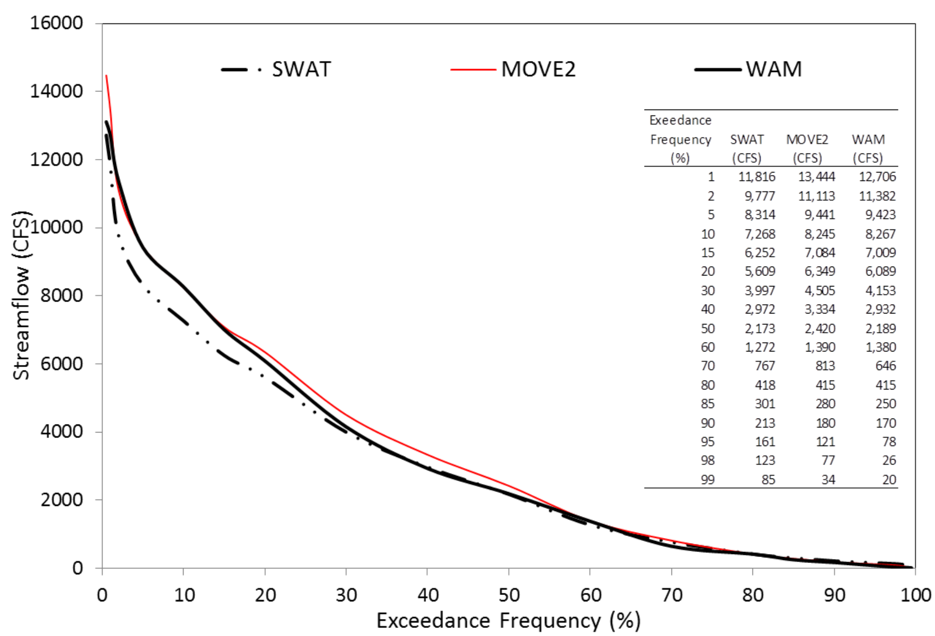

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 668 | 933 | 849 |
| 2 | 552 | 781 | 797 |
| 5 | 429 | 619 | 656 |
| 10 | 268 | 408 | 496 |
| 15 | 231 | 359 | 425 |
| 20 | 179 | 291 | 381 |
| 30 | 124 | 219 | 260 |
| 40 | 66 | 143 | 164 |
| 50 | 32 | 98 | 117 |
| 60 | 14 | 74 | 85 |
| 70 | 3 | 60 | 59 |
| 80 | 1 | 57 | 41 |
| 85 | 0 | 57 | 33 |
| 90 | 0 | 56 | 25 |
| 95 | 0 | 56 | 10 |
| 98 | 0 | 56 | 7 |
| 99 | 0 | 56 | 5 |

Figure 4.57 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at BSBS in the Sabine River Basin



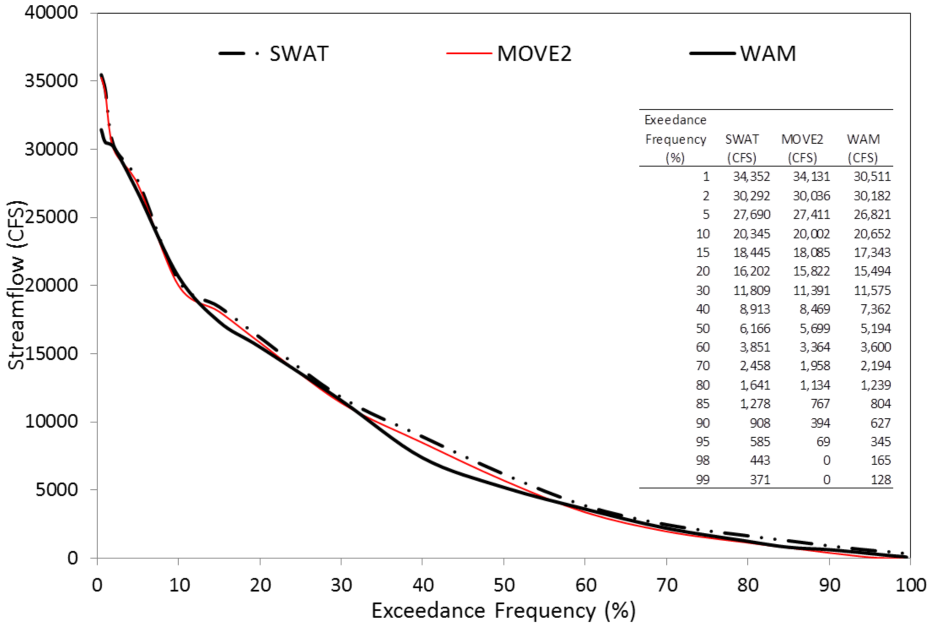

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 9,325 | 11,644 | 12,364 |
| 2 | 6,497 | 7,923 | 9,644 |
| 5 | 6,114 | 7,418 | 8,270 |
| 10 | 5,065 | 6,039 | 6,091 |
| 15 | 4,241 | 4,954 | 4,993 |
| 20 | 3,753 | 4,313 | 4,403 |
| 30 | 2,971 | 3,283 | 3,090 |
| 40 | 2,251 | 2,335 | 1,998 |
| 50 | 1,687 | 1,594 | 1,481 |
| 60 | 1,299 | 1,083 | 915 |
| 70 | 944 | 615 | 416 |
| 80 | 484 | 11 | 238 |
| 85 | 316 | 0 | 153 |
| 90 | 181 | 0 | 104 |
| 95 | 112 | 0 | 48 |
| 98 | 58 | 0 | 19 |
| 99 | 34 | 0 | 14 |

Figure 4.58 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at SRGW in the Sabine River Basin



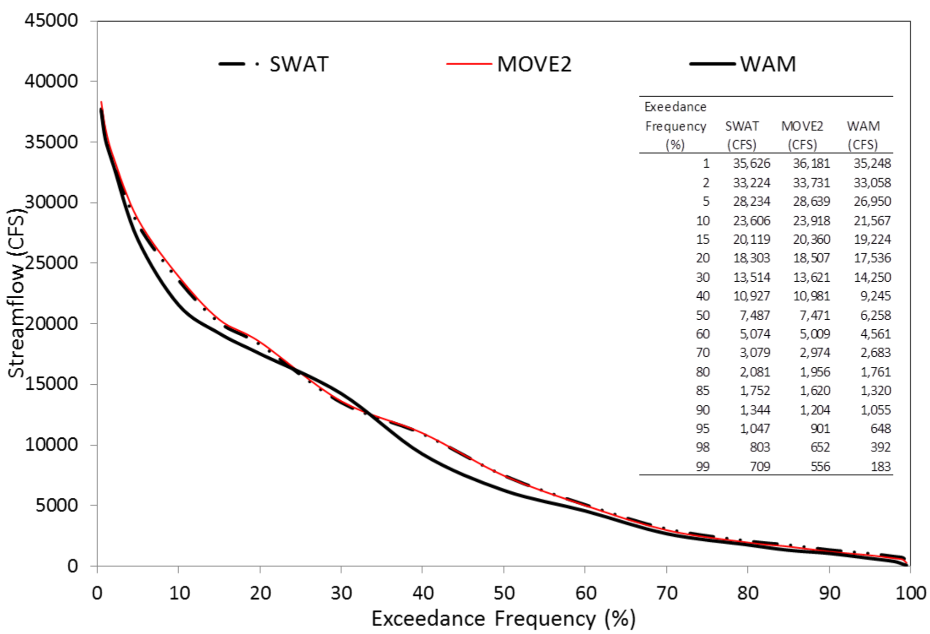

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 11,816 | 13,444 | 12,706 |
| 2 | 9,777 | 11,113 | 11,382 |
| 5 | 8,314 | 9,441 | 9,423 |
| 10 | 7,268 | 8,245 | 8,267 |
| 15 | 6,252 | 7,084 | 7,009 |
| 20 | 5,609 | 6,349 | 6,089 |
| 30 | 3,997 | 4,505 | 4,153 |
| 40 | 2,972 | 3,334 | 2,932 |
| 50 | 2,173 | 2,420 | 2,189 |
| 60 | 1,272 | 1,390 | 1,380 |
| 70 | 767 | 813 | 646 |
| 80 | 418 | 415 | 415 |
| 85 | 301 | 280 | 250 |
| 90 | 213 | 180 | 170 |
| 95 | 161 | 121 | 78 |
| 98 | 123 | 77 | 26 |
| 99 | 85 | 34 | 20 |

Figure 4.59 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at SRBE in the Sabine River Basin



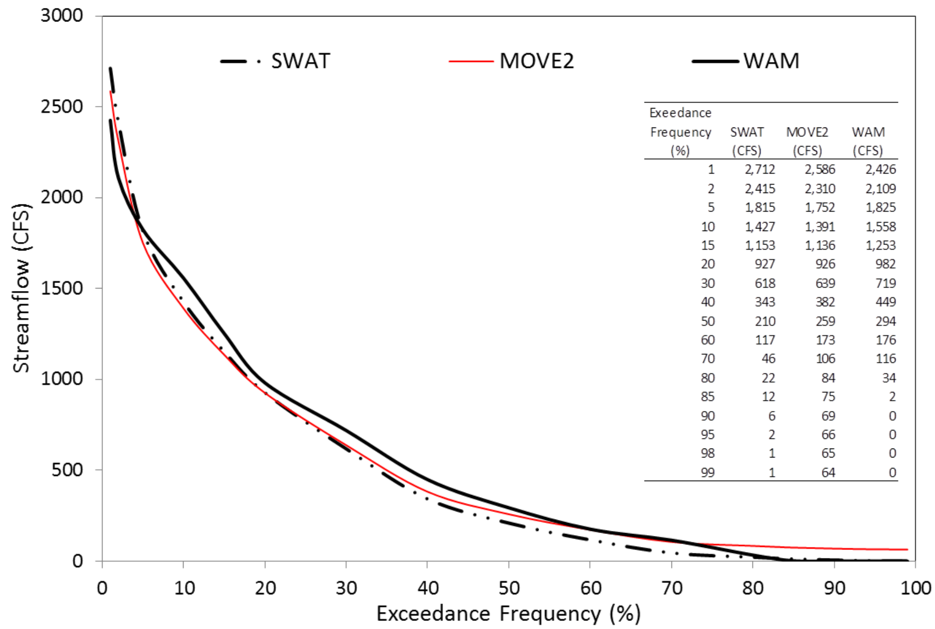

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 34,352 | 34,131 | 30,511 |
| 2 | 30,292 | 30,036 | 30,182 |
| 5 | 27,690 | 27,411 | 26,821 |
| 10 | 20,345 | 20,002 | 20,652 |
| 15 | 18,445 | 18,085 | 17,343 |
| 20 | 16,202 | 15,822 | 15,494 |
| 30 | 11,809 | 11,391 | 11,575 |
| 40 | 8,913 | 8,469 | 7,362 |
| 50 | 6,166 | 5,699 | 5,194 |
| 60 | 3,851 | 3,364 | 3,600 |
| 70 | 2,458 | 1,958 | 2,194 |
| 80 | 1,641 | 1,134 | 1,239 |
| 85 | 1,278 | 767 | 804 |
| 90 | 908 | 394 | 627 |
| 95 | 585 | 69 | 345 |
| 98 | 443 | 0 | 165 |
| 99 | 371 | 0 | 128 |

Figure 4.60 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at SRBW in the Sabine River Basin



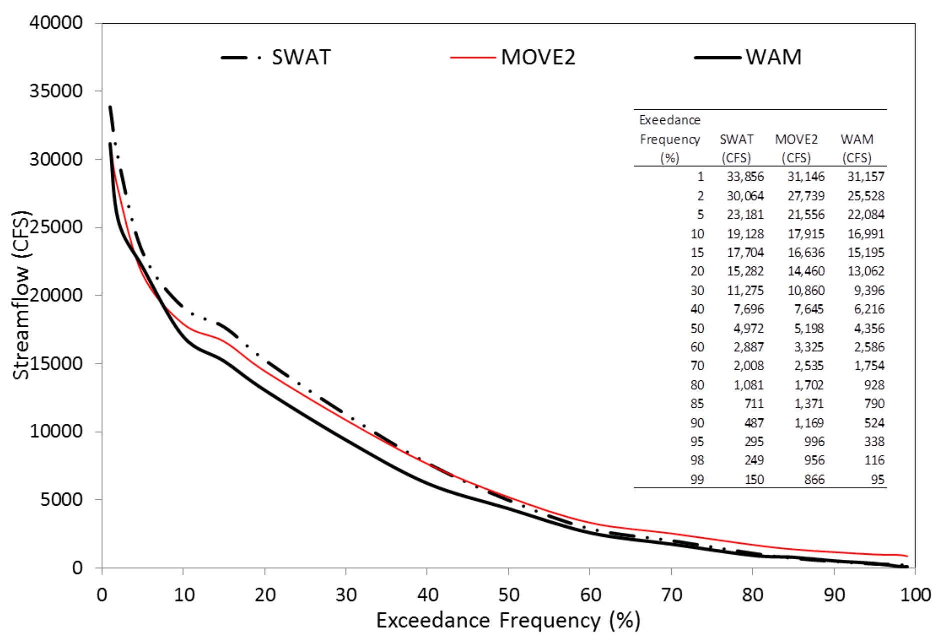

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 35,626 | 36,181 | 35,248 |
| 2 | 33,224 | 33,731 | 33,058 |
| 5 | 28,234 | 28,639 | 26,950 |
| 10 | 23,606 | 23,918 | 21,567 |
| 15 | 20,119 | 20,360 | 19,224 |
| 20 | 18,303 | 18,507 | 17,536 |
| 30 | 13,514 | 13,621 | 14,250 |
| 40 | 10,927 | 10,981 | 9,245 |
| 50 | 7,487 | 7,471 | 6,258 |
| 60 | 5,074 | 5,009 | 4,561 |
| 70 | 3,079 | 2,974 | 2,683 |
| 80 | 2,081 | 1,956 | 1,761 |
| 85 | 1,752 | 1,620 | 1,320 |
| 90 | 1,344 | 1,204 | 1,055 |
| 95 | 1,047 | 901 | 648 |
| 98 | 803 | 652 | 392 |
| 99 | 709 | 556 | 183 |

Figure 4.61 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at SRRL in the Sabine River Basin



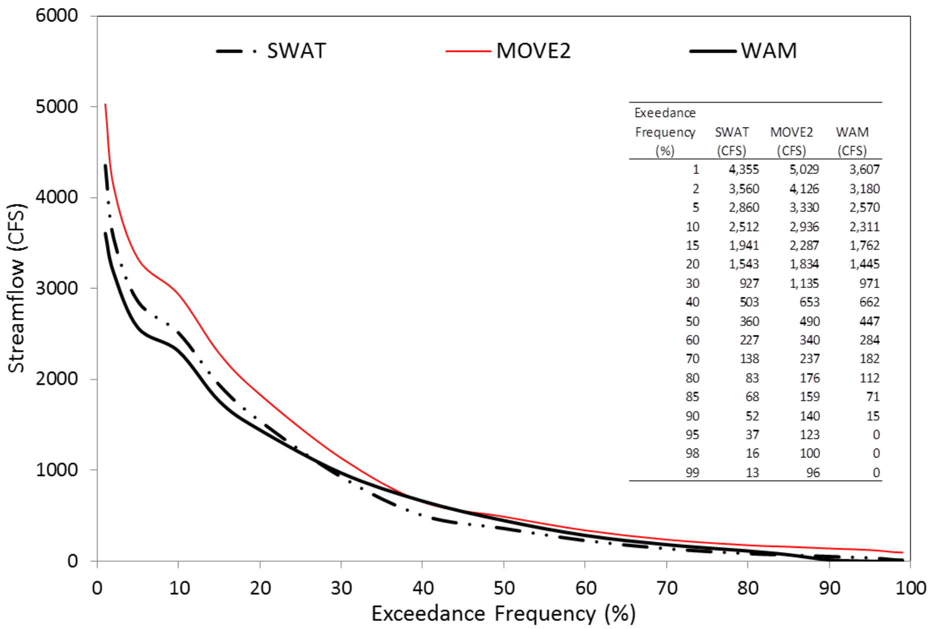

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 2,712 | 2,586 | 2,426 |
| 2 | 2,415 | 2,310 | 2,109 |
| 5 | 1,815 | 1,752 | 1,825 |
| 10 | 1,427 | 1,391 | 1,558 |
| 15 | 1,153 | 1,136 | 1,253 |
| 20 | 927 | 926 | 982 |
| 30 | 618 | 639 | 719 |
| 40 | 343 | 382 | 449 |
| 50 | 210 | 259 | 294 |
| 60 | 117 | 173 | 176 |
| 70 | 46 | 106 | 116 |
| 80 | 22 | 84 | 34 |
| 85 | 12 | 75 | 2 |
| 90 | 6 | 69 | 0 |
| 95 | 2 | 66 | 0 |
| 98 | 1 | 65 | 0 |
| 99 | 1 | 64 | 0 |

Figure 4.62 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at ATCH in the Neches River Basin



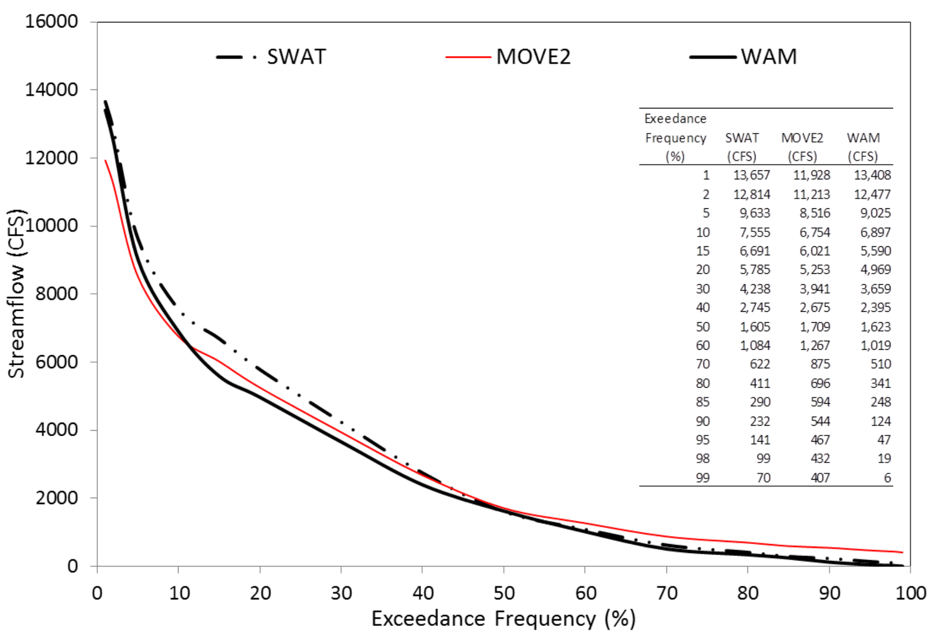

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 33,856 | 31,146 | 31,157 |
| 2 | 30,064 | 27,739 | 25,528 |
| 5 | 23,181 | 21,556 | 22,084 |
| 10 | 19,128 | 17,915 | 16,991 |
| 15 | 17,704 | 16,636 | 15,195 |
| 20 | 15,282 | 14,460 | 13,062 |
| 30 | 11,275 | 10,860 | 9,396 |
| 40 | 7,696 | 7,645 | 6,216 |
| 50 | 4,972 | 5,198 | 4,356 |
| 60 | 2,887 | 3,325 | 2,586 |
| 70 | 2,008 | 2,535 | 1,754 |
| 80 | 1,081 | 1,702 | 928 |
| 85 | 711 | 1,371 | 790 |
| 90 | 487 | 1,169 | 524 |
| 95 | 295 | 996 | 338 |
| 98 | 249 | 956 | 116 |
| 99 | 150 | 866 | 95 |

Figure 4.63 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at NEEV in the Neches River Basin



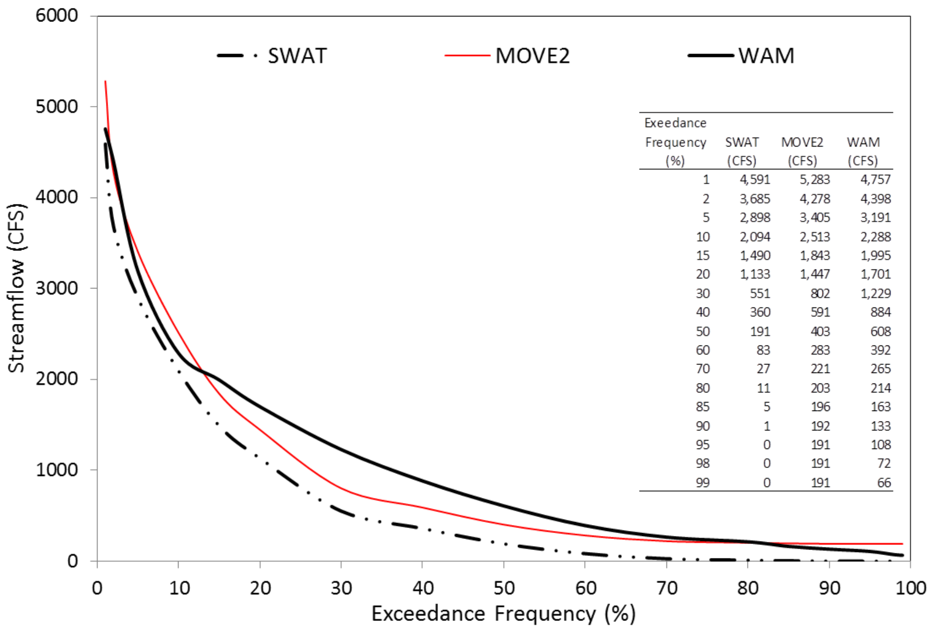

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 4,355 | 5,029 | 3,607 |
| 2 | 3,560 | 4,126 | 3,180 |
| 5 | 2,860 | 3,330 | 2,570 |
| 10 | 2,512 | 2,936 | 2,311 |
| 15 | 1,941 | 2,287 | 1,762 |
| 20 | 1,543 | 1,834 | 1,445 |
| 30 | 927 | 1,135 | 971 |
| 40 | 503 | 653 | 662 |
| 50 | 360 | 490 | 447 |
| 60 | 227 | 340 | 284 |
| 70 | 138 | 237 | 182 |
| 80 | 83 | 176 | 112 |
| 85 | 68 | 159 | 71 |
| 90 | 52 | 140 | 15 |
| 95 | 37 | 123 | 0 |
| 98 | 16 | 100 | 0 |
| 99 | 13 | 96 | 0 |

Figure 4.64 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at NENE in the Neches River Basin



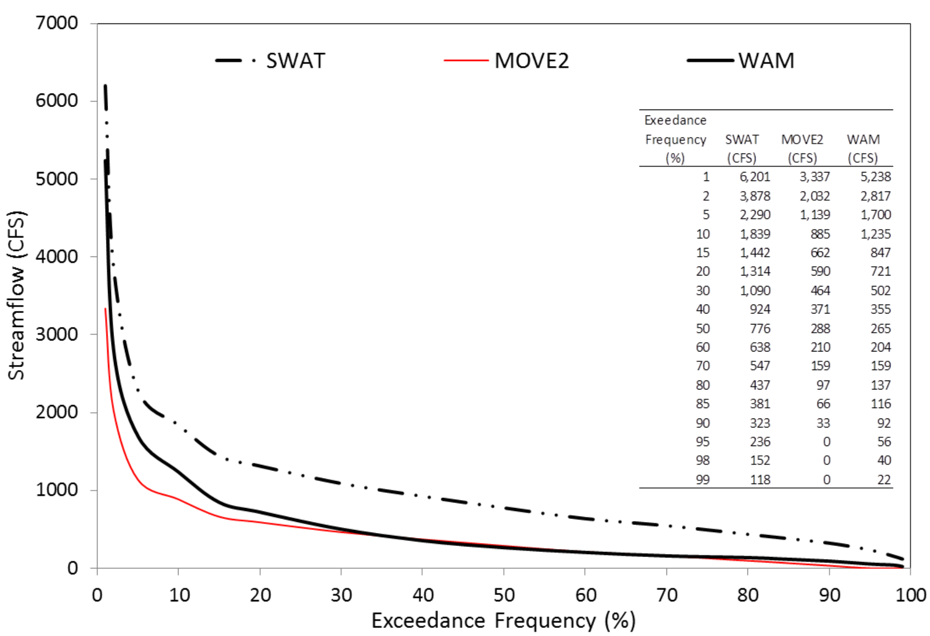

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 13,657 | 11,928 | 13,408 |
| 2 | 12,814 | 11,213 | 12,477 |
| 5 | 9,633 | 8,516 | 9,025 |
| 10 | 7,555 | 6,754 | 6,897 |
| 15 | 6,691 | 6,021 | 5,590 |
| 20 | 5,785 | 5,253 | 4,969 |
| 30 | 4,238 | 3,941 | 3,659 |
| 40 | 2,745 | 2,675 | 2,395 |
| 50 | 1,605 | 1,709 | 1,623 |
| 60 | 1,084 | 1,267 | 1,019 |
| 70 | 622 | 875 | 510 |
| 80 | 411 | 696 | 341 |
| 85 | 290 | 594 | 248 |
| 90 | 232 | 544 | 124 |
| 95 | 141 | 467 | 47 |
| 98 | 99 | 432 | 19 |
| 99 | 70 | 407 | 6 |

Figure 4.65 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at NERO in the Neches River Basin



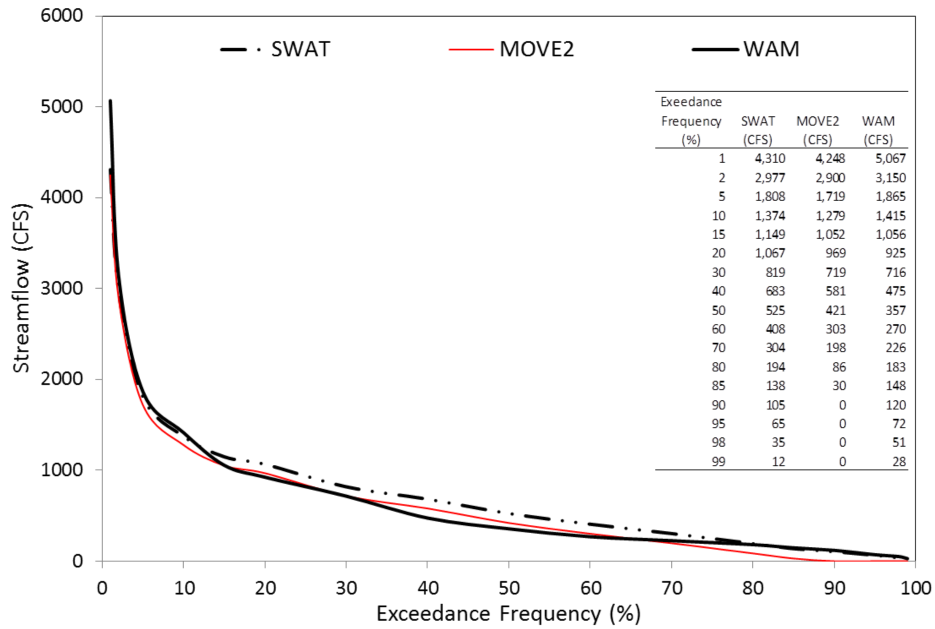

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 4,591 | 5,283 | 4,757 |
| 2 | 3,685 | 4,278 | 4,398 |
| 5 | 2,898 | 3,405 | 3,191 |
| 10 | 2,094 | 2,513 | 2,288 |
| 15 | 1,490 | 1,843 | 1,995 |
| 20 | 1,133 | 1,447 | 1,701 |
| 30 | 551 | 802 | 1,229 |
| 40 | 360 | 591 | 884 |
| 50 | 191 | 403 | 608 |
| 60 | 83 | 283 | 392 |
| 70 | 27 | 221 | 265 |
| 80 | 11 | 203 | 214 |
| 85 | 5 | 196 | 163 |
| 90 | 1 | 192 | 133 |
| 95 | 0 | 191 | 108 |
| 98 | 0 | 191 | 72 |
| 99 | 0 | 191 | 66 |

Figure 4.66 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at VIKO in the Neches River Basin



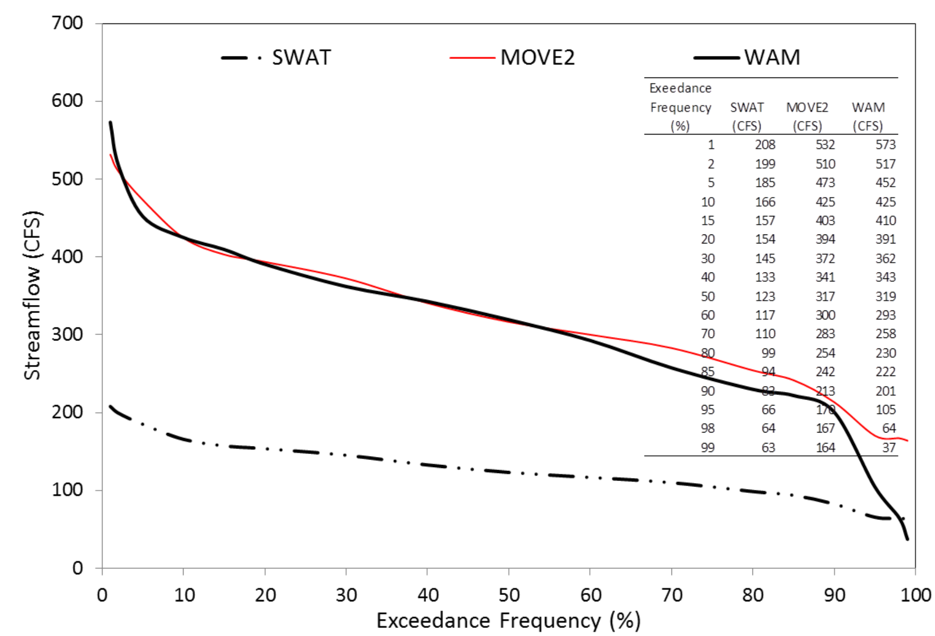

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 6,201 | 3,337 | 5,238 |
| 2 | 3,878 | 2,032 | 2,817 |
| 5 | 2,290 | 1,139 | 1,700 |
| 10 | 1,839 | 885 | 1,235 |
| 15 | 1,442 | 662 | 847 |
| 20 | 1,314 | 590 | 721 |
| 30 | 1,090 | 464 | 502 |
| 40 | 924 | 371 | 355 |
| 50 | 776 | 288 | 265 |
| 60 | 638 | 210 | 204 |
| 70 | 547 | 159 | 159 |
| 80 | 437 | 97 | 137 |
| 85 | 381 | 66 | 116 |
| 90 | 323 | 33 | 92 |
| 95 | 236 | 0 | 56 |
| 98 | 152 | 0 | 40 |
| 99 | 118 | 0 | 22 |

Figure 4.67 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP02 in the GSA River Basins



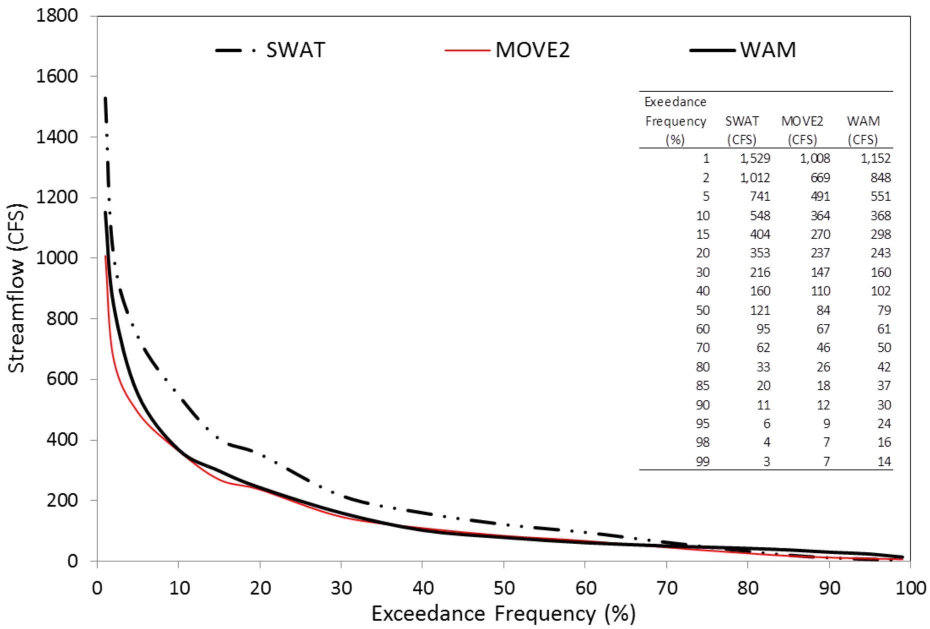

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 4,310 | 4,248 | 5,067 |
| 2 | 2,977 | 2,900 | 3,150 |
| 5 | 1,808 | 1,719 | 1,865 |
| 10 | 1,374 | 1,279 | 1,415 |
| 15 | 1,149 | 1,052 | 1,056 |
| 20 | 1,067 | 969 | 925 |
| 30 | 819 | 719 | 716 |
| 40 | 683 | 581 | 475 |
| 50 | 525 | 421 | 357 |
| 60 | 408 | 303 | 270 |
| 70 | 304 | 198 | 226 |
| 80 | 194 | 86 | 183 |
| 85 | 138 | 30 | 148 |
| 90 | 105 | 0 | 120 |
| 95 | 65 | 0 | 72 |
| 98 | 35 | 0 | 51 |
| 99 | 12 | 0 | 28 |

Figure 4.68 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP04 in the GSA River Basins



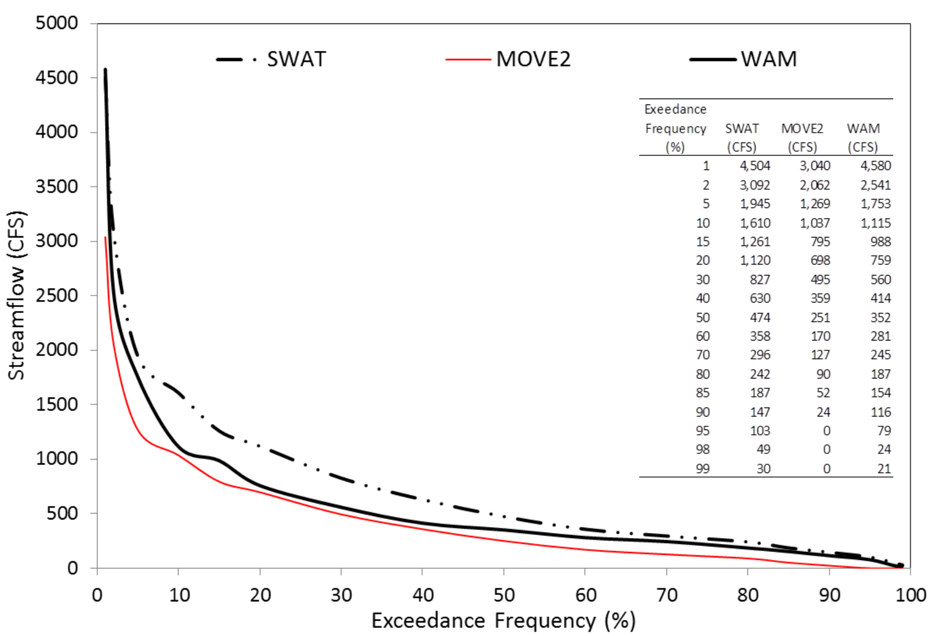

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 208 | 532 | 573 |
| 2 | 199 | 510 | 517 |
| 5 | 185 | 473 | 452 |
| 10 | 166 | 425 | 425 |
| 15 | 157 | 403 | 410 |
| 20 | 154 | 394 | 391 |
| 30 | 145 | 372 | 362 |
| 40 | 133 | 341 | 343 |
| 50 | 123 | 317 | 319 |
| 60 | 117 | 300 | 293 |
| 70 | 110 | 283 | 258 |
| 80 | 99 | 254 | 230 |
| 85 | 94 | 242 | 222 |
| 90 | 83 | 213 | 201 |
| 95 | 66 | 170 | 105 |
| 98 | 64 | 167 | 64 |
| 99 | 63 | 164 | 37 |

Figure 4.69 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP05 in the GSA River Basins



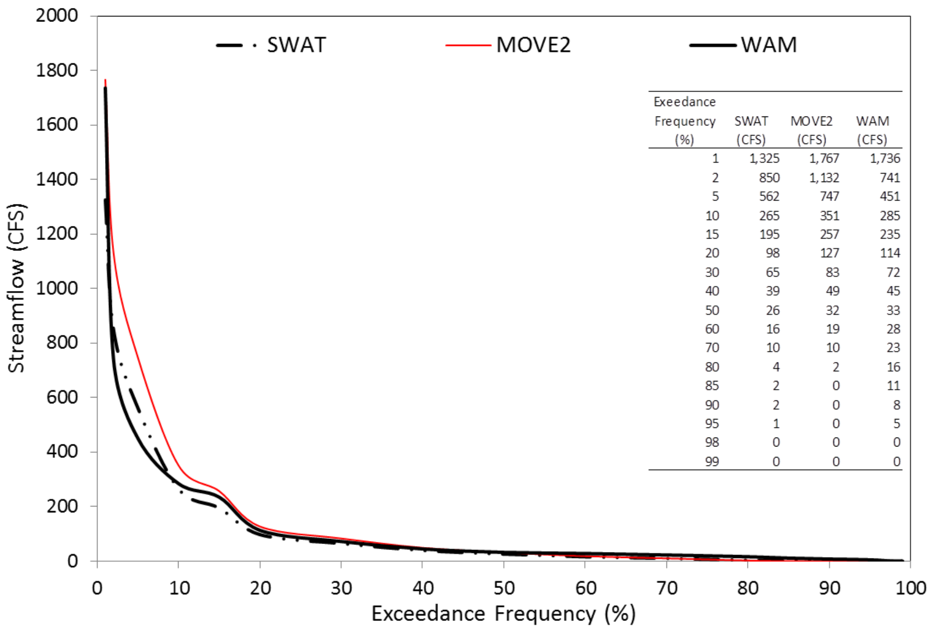

| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 1,529 | 1,008 | 1,152 |
| 2 | 1,012 | 669 | 848 |
| 5 | 741 | 491 | 551 |
| 10 | 548 | 364 | 368 |
| 15 | 404 | 270 | 298 |
| 20 | 353 | 237 | 243 |
| 30 | 216 | 147 | 160 |
| 40 | 160 | 110 | 102 |
| 50 | 121 | 84 | 79 |
| 60 | 95 | 67 | 61 |
| 70 | 62 | 46 | 50 |
| 80 | 33 | 26 | 42 |
| 85 | 20 | 18 | 37 |
| 90 | 11 | 12 | 30 |
| 95 | 6 | 9 | 24 |
| 98 | 4 | 7 | 16 |
| 99 | 3 | 7 | 14 |

Figure 4.70 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP08 in the GSA River Basins




| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 4,504 | 3,040 | 4,580 |
| 2 | 3,092 | 2,062 | 2,541 |
| 5 | 1,945 | 1,269 | 1,753 |
| 10 | 1,610 | 1,037 | 1,115 |
| 15 | 1,261 | 795 | 988 |
| 20 | 1,120 | 698 | 759 |
| 30 | 827 | 495 | 560 |
| 40 | 630 | 359 | 414 |
| 50 | 474 | 251 | 352 |
| 60 | 358 | 170 | 281 |
| 70 | 296 | 127 | 245 |
| 80 | 242 | 90 | 187 |
| 85 | 187 | 52 | 154 |
| 90 | 147 | 24 | 116 |
| 95 | 103 | 0 | 79 |
| 98 | 49 | 0 | 24 |
| 99 | 30 | 0 | 21 |

Figure 4.71 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP32 in the GSA River Basins




| Exeedance Frequency (%) | SWAT (CFS) | MOVE2 (CFS) | WAM (CFS) |
|---|---|---|---|
| 1 | 1,325 | 1,767 | 1,736 |
| 2 | 850 | 1,132 | 741 |
| 5 | 562 | 747 | 451 |
| 10 | 265 | 351 | 285 |
| 15 | 195 | 257 | 235 |
| 20 | 98 | 127 | 114 |
| 30 | 65 | 83 | 72 |
| 40 | 39 | 49 | 45 |
| 50 | 26 | 32 | 33 |
| 60 | 16 | 19 | 28 |
| 70 | 10 | 10 | 23 |
| 80 | 4 | 2 | 16 |
| 85 | 2 | 0 | 11 |
| 90 | 2 | 0 | 8 |
| 95 | 1 | 0 | 5 |
| 98 | 0 | 0 | 0 |
| 99 | 0 | 0 | 0 |

Figure 4.72 Flow Duration Curves (SWAT: SWAT flow, MOVE2: Infilled flow by MOVE2, and WAM: Naturalized flow) and Flow Frequencies at CP35 in the GSA River Basins

# CHAPTER V

# REFINEMENT OF METHODS FOR DEVELOPING NATURALIZED FLOWS AT UNGAUGED SITES BASED ON FLOWS AT GAUGED SITES

## 5.1 Naturalized Flow Datasets

The WAM datasets of the three case study basins serve as sample data pairs in this section. In addition, the WAM dataset in the Trinity River Basin also serves as the pairs to evaluate the improvement of these suggested methods in this research. The characteristic and WAM datasets of the Trinity River Basin are referred to in *Daily Water Availability Model for the Trinity River Basin* (Hoffpauir *et al.*, 2014). The periods-of-analysis of the naturalized flows at each primary control point are 1940-1998 for the Sabine WAM, 1940-1996 for the Neches WAM, 1934-1989 for the GSA WAM, and 1940-1998 for the Trinity WAM, respectively.

In the pair of control points, one control point is assumed an ungauged site Y, and another control point is assumed a gauged site X. Its opposite pair is also available in pair sampling from WAM dataset. The pairs with high linear correlation coefficient ($r > 0.91$) are only obtained from the WAM datasets for removing biases caused by low linear correlation of both datasets when a linear transfer method is used for developing flow sequences at ungauged based on flows at gauged sites.

The WAM dataset of the Sabine River Basin (the Sabine WAM) has the monthly naturalized flows at 18 primary control points. There are 153 possible unordered pair samplings from 18 primary control points. The unordered 26 pairs have more than 0.91 correlation coefficients (r) as listed in Table 5.1. There are monthly naturalized flows at 20 primary control points in the WAM dataset of the Neches River Basin (the Neches WAM). These control points have 190 possible unordered pair samplings. The 79 unordered pairs with acceptable correlation coefficient like the Sabine River Basin are chosen, as listed in Table 5.2. The WAM datasets of the GSA River Basins (the GSA WAM) have 45 primary control points, and 990 unordered pair samplings are possible, but 58 pairs have acceptable correlation coefficients as listed in Table 5.3. The WAM dataset of the Trinity River Basin (the Trinity WAM) has 40 primary control points. 708 unordered pair samplings are available, but 194 pairs have more than 0.9 correlation coefficients as listed in Table 5.4.

Table 5.1 Selected Pairs from the WAM dataset in the Sabine River Basin

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|
| 1 | SRWP | SRMN | 0.98 |
| 2 | SRMN | SRWP | 0.98 |
| 3 | SRMN | LFQT | 0.92 |
| 4 | SRMN | SRGW | 0.94 |
| 5 | LFQT | SRMN | 0.92 |
| 6 | SRGW | SRMN | 0.94 |
| 7 | SRGW | SRBE | 0.96 |
| 8 | SRGW | SRLP | 0.93 |
| 9 | SRBE | SRGW | 0.96 |
| 10 | SRBE | SRLP | 0.98 |
| 11 | MCTT | MBGR | 0.98 |
| 12 | MBGR | MCTT | 0.98 |
| 13 | SRLP | SRGW | 0.93 |
| 14 | SRLP | SRBE | 0.98 |
| 15 | SRLP | SRBU | 0.91 |
| 16 | SRBU | SRLP | 0.91 |
| 17 | SRBU | SRRL | 0.98 |
| 18 | SRBU | SRSL | 0.98 |
| 19 | SRBW | SRRL | 0.99 |
| 20 | SRBW | SRSL | 0.98 |
| 21 | SRRL | SRBU | 0.98 |
| 22 | SRRL | SRBW | 0.99 |
| 23 | SRRL | SRSL | 1.00 |
| 24 | SRSL | SRBU | 0.98 |
| 25 | SRSL | SRBW | 0.98 |
| 26 | SRSL | SRRL | 1.00 |

Table 5.2 Selected Pairs from the WAM dataset in the Neches River Basin

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|---|---|---|---|
| 1 | KIBR | NEPA | 0.97 | 28 | ANAL | ANSR | 0.93 |
| 2 | KIBR | NENE | 0.96 | 29 | ANAL | NETB | 0.92 |
| 3 | NEPA | KIBR | 0.97 | 30 | ANAL | NEEV | 0.91 |
| 4 | NEPA | NENE | 0.98 | 31 | ANLU | NEAL | 0.92 |
| 5 | NEPA | NEAL | 0.92 | 32 | ANLU | NEDI | 0.94 |
| 6 | NENE | KIBR | 0.96 | 33 | ANLU | MUJA | 0.93 |
| 7 | NENE | NEPA | 0.98 | 34 | ANLU | EFACU | 0.94 |
| 8 | NENE | NEAL | 0.95 | 35 | ANLU | ANAL | 0.99 |
| 9 | NEAL | NEPA | 0.92 | 36 | ANLU | ANSR | 0.95 |
| 10 | NEAL | NENE | 0.95 | 37 | ANLU | NETB | 0.94 |
| 11 | NEAL | NEDI | 0.97 | 38 | ANLU | NEEV | 0.93 |
| 12 | NEDI | NEAL | 0.97 | 39 | ATCH | AYSA | 0.92 |
| 13 | NEDI | NERO | 0.98 | 40 | ATCH | ANSR | 0.93 |
| 14 | NEDI | NEBA | 0.92 | 41 | AYSA | ATCH | 0.92 |
| 15 | NEDI | NESL | 0.92 | 42 | AYSA | ANSR | 0.93 |
| 16 | NERO | NEDI | 0.98 | 43 | ANSR | NEDI | 0.92 |
| 17 | NERO | ANSR | 0.94 | 44 | ANSR | NERO | 0.94 |
| 18 | NERO | NETB | 0.98 | 45 | ANSR | ANAL | 0.93 |
| 19 | NERO | NEEV | 0.98 | 46 | ANSR | ANLU | 0.95 |
| 20 | NERO | NEBA | 0.96 | 47 | ANSR | ATCH | 0.93 |
| 21 | NERO | NESL | 0.96 | 48 | ANSR | AYSA | 0.93 |
| 22 | MUJA | ANAL | 0.94 | 49 | ANSR | NETB | 0.98 |
| 23 | MUJA | ANLU | 0.93 | 50 | ANSR | NEEV | 0.98 |
| 24 | EFACU | ANAL | 0.93 | 51 | ANSR | NEBA | 0.96 |
| 25 | EFACU | ANLU | 0.94 | 52 | ANSR | NESL | 0.95 |
| 26 | ANAL | MUJA | 0.94 | 53 | NETB | NEDI | 0.95 |
| 27 | ANAL | ANLU | 0.99 | 54 | NETB | NERO | 0.98 |

Table 5.2 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|
| 55 | NETB | ANAL | 0.92 |
| 56 | NETB | ANLU | 0.94 |
| 57 | NETB | ANSR | 0.98 |
| 58 | NETB | NEEV | 1.00 |
| 59 | NETB | NEBA | 0.98 |
| 60 | NETB | NESL | 0.98 |
| 61 | NEEV | NEDI | 0.95 |
| 62 | NEEV | NERO | 0.98 |
| 63 | NEEV | ANAL | 0.91 |
| 64 | NEEV | ANLU | 0.93 |
| 65 | NEEV | ANSR | 0.98 |
| 66 | NEEV | NEBA | 0.99 |
| 67 | NEEV | NESL | 0.98 |
| 68 | NEBA | NEDI | 0.92 |
| 69 | NEBA | NERO | 0.96 |
| 70 | NEBA | ANSR | 0.96 |
| 71 | NEBA | NETB | 0.98 |
| 72 | NEBA | NEEV | 0.99 |
| 73 | NEBA | NESL | 1.00 |
| 74 | NESL | NEDI | 0.92 |
| 75 | NESL | NERO | 0.96 |
| 76 | NESL | ANSR | 0.95 |
| 77 | NESL | NETB | 0.98 |
| 78 | NESL | NEEV | 0.98 |
| 79 | NESL | NEBA | 1.00 |

Table 5.3 Selected Pairs from the WAM dataset in the GSA River Basins

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|---|---|---|---|
| 1 | CP02 | CP01 | 0.91 | 33 | CP263 | CP25 | 0.99 |
| 2 | CP01 | CP02 | 0.91 | 34 | CP25 | CP261 | 0.99 |
| 3 | CP03 | CP02 | 0.99 | 35 | CP25 | CP262 | 0.99 |
| 4 | CP04 | CP02 | 0.98 | 36 | CP21 | CP27 | 0.94 |
| 5 | CP06 | CP02 | 0.94 | 37 | CP23 | CP27 | 0.94 |
| 6 | CP02 | CP03 | 0.99 | 38 | CP28 | CP27 | 0.99 |
| 7 | CP04 | CP03 | 0.99 | 39 | CP29 | CP27 | 0.94 |
| 8 | CP06 | CP03 | 0.96 | 40 | CP32 | CP27 | 0.92 |
| 9 | CP02 | CP04 | 0.98 | 41 | CP21 | CP28 | 0.92 |
| 10 | CP03 | CP04 | 0.99 | 42 | CP23 | CP28 | 0.92 |
| 11 | CP06 | CP04 | 0.98 | 43 | CP27 | CP28 | 0.99 |
| 12 | CP02 | CP06 | 0.94 | 44 | CP29 | CP28 | 0.95 |
| 13 | CP03 | CP06 | 0.96 | 45 | CP32 | CP28 | 0.94 |
| 14 | CP04 | CP06 | 0.98 | 46 | CP27 | CP29 | 0.94 |
| 15 | CP09 | CP08 | 0.99 | 47 | CP28 | CP29 | 0.95 |
| 16 | CP10 | CP08 | 0.91 | 48 | CP32 | CP29 | 0.98 |
| 17 | CP08 | CP09 | 0.99 | 49 | CP27 | CP32 | 0.92 |
| 18 | CP10 | CP09 | 0.92 | 50 | CP28 | CP32 | 0.94 |
| 19 | CP08 | CP10 | 0.91 | 51 | CP29 | CP32 | 0.98 |
| 20 | CP09 | CP10 | 0.92 | 52 | CP38 | CP37 | 0.93 |
| 21 | CP15 | CP14 | 1.00 | 53 | CPEST | CP37 | 0.92 |
| 22 | CP38 | CP14 | 0.95 | 54 | CP14 | CP38 | 0.95 |
| 23 | CPEST | CP14 | 0.94 | 55 | CP15 | CP38 | 0.95 |
| 24 | CP14 | CP15 | 1.00 | 56 | CP37 | CP38 | 0.93 |
| 25 | CP38 | CP15 | 0.95 | 57 | CP14 | CPEST | 0.94 |
| 26 | CPEST | CP15 | 0.94 | 58 | CP15 | CPEST | 0.94 |
| 27 | CP27 | CP21 | 0.94 | | | | |
| 28 | CP28 | CP21 | 0.92 | | | | |
| 29 | CP27 | CP23 | 0.94 | | | | |
| 30 | CP28 | CP23 | 0.92 | | | | |
| 31 | CP261 | CP25 | 0.99 | | | | |
| 32 | CP262 | CP25 | 0.99 | | | | |

Table 5.4 Selected Pairs from the WAM dataset in the Trinity River Basin

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|---|---|---|---|
| 1 | 8WTJA | 8WTBO | 0.93 | 35 | 8ELSA | 8TRDA | 0.91 |
| 2 | 8BSBR | 8WTBO | 0.93 | 36 | 8IDPP | 8ELSA | 0.92 |
| 3 | 8WTBO | 8WTJA | 0.93 | 37 | 8IDPP | 8CLSA | 0.92 |
| 4 | 8WTBO | 8BSBR | 0.93 | 38 | 8IDPP | 8ELLE | 0.98 |
| 5 | 8WTBO | 8WTFW | 0.97 | 39 | 8IDPP | 8DNGR | 0.93 |
| 6 | 8WTBO | 8WTGP | 0.95 | 40 | 8IDPP | 8TRDA | 0.95 |
| 7 | 8WTBO | 8DNJU | 0.94 | 41 | 8IDPP | 8TRRS | 0.93 |
| 8 | 8WTBO | 8DNGR | 0.92 | 42 | 8CLSA | 8ELSA | 0.98 |
| 9 | 8WTBO | 8TRDA | 0.92 | 43 | 8CLSA | 8IDPP | 0.92 |
| 10 | 8CTAL | 8CTBE | 0.97 | 44 | 8CLSA | 8ELLE | 0.94 |
| 11 | 8CTAL | 8CTFW | 0.97 | 45 | 8CLSA | 8DNJU | 0.97 |
| 12 | 8CTBE | 8CTAL | 0.97 | 46 | 8CLSA | 8DNGR | 0.95 |
| 13 | 8CTBE | 8CTFW | 0.99 | 47 | 8CLSA | 8TRDA | 0.93 |
| 14 | 8CTFW | 8CTAL | 0.97 | 48 | 8ELLE | 8ELSA | 0.92 |
| 15 | 8CTFW | 8CTBE | 0.99 | 49 | 8ELLE | 8IDPP | 0.98 |
| 16 | 8WTFW | 8WTBO | 0.97 | 50 | 8ELLE | 8CLSA | 0.94 |
| 17 | 8WTFW | 8WTGP | 0.99 | 51 | 8ELLE | 8DNJU | 0.94 |
| 18 | 8WTFW | 8DNJU | 0.94 | 52 | 8ELLE | 8DNGR | 0.96 |
| 19 | 8WTFW | 8DNGR | 0.94 | 53 | 8ELLE | 8TRDA | 0.97 |
| 20 | 8WTFW | 8TRDA | 0.96 | 54 | 8ELLE | 8ETMK | 0.91 |
| 21 | 8WTFW | 8TRRS | 0.93 | 55 | 8ELLE | 8TRRS | 0.95 |
| 22 | 8WTFW | 8TRTR | 0.92 | 56 | 8ELLE | 8TRTR | 0.93 |
| 23 | 8WTGP | 8WTBO | 0.95 | 57 | 8DNJU | 8WTBO | 0.94 |
| 24 | 8WTGP | 8WTFW | 0.99 | 58 | 8DNJU | 8WTFW | 0.94 |
| 25 | 8WTGP | 8DNJU | 0.92 | 59 | 8DNJU | 8WTGP | 0.92 |
| 26 | 8WTGP | 8DNGR | 0.93 | 60 | 8DNJU | 8ELSA | 0.94 |
| 27 | 8WTGP | 8TRDA | 0.97 | 61 | 8DNJU | 8CLSA | 0.97 |
| 28 | 8WTGP | 8TRRS | 0.95 | 62 | 8DNJU | 8ELLE | 0.94 |
| 29 | 8WTGP | 8TRTR | 0.94 | 63 | 8DNJU | 8DNGR | 0.98 |
| 30 | 8ELSA | 8IDPP | 0.92 | 64 | 8DNJU | 8TRDA | 0.95 |
| 31 | 8ELSA | 8CLSA | 0.98 | 65 | 8DNGR | 8WTBO | 0.92 |
| 32 | 8ELSA | 8ELLE | 0.92 | 66 | 8DNGR | 8WTFW | 0.94 |
| 33 | 8ELSA | 8DNJU | 0.94 | 67 | 8DNGR | 8WTGP | 0.93 |
| 34 | 8ELSA | 8DNGR | 0.93 | 68 | 8DNGR | 8ELSA | 0.93 |

Table 5.4 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|---|---|---|---|
| 69 | 8DNGR | 8IDPP | 0.93 | 103 | 8ETLA | 8SGPR | 0.96 |
| 70 | 8DNGR | 8CLSA | 0.95 | 104 | 8ETLA | 8ETFO | 0.98 |
| 71 | 8DNGR | 8ELLE | 0.96 | 105 | 8ETLA | 8ETCR | 0.98 |
| 72 | 8DNGR | 8DNJU | 0.98 | 106 | 8ETLA | 8TRRS | 0.92 |
| 73 | 8DNGR | 8TRDA | 0.97 | 107 | 8ETLA | 8TRTR | 0.92 |
| 74 | 8DNGR | 8TRRS | 0.93 | 108 | 8ETFO | 8ETMK | 0.96 |
| 75 | 8DNGR | 8TRTR | 0.92 | 109 | 8ETFO | 8SGPR | 0.96 |
| 76 | 8TRDA | 8WTBO | 0.92 | 110 | 8ETFO | 8ETLA | 0.98 |
| 77 | 8TRDA | 8WTFW | 0.96 | 111 | 8ETFO | 8ETCR | 1.00 |
| 78 | 8TRDA | 8WTGP | 0.97 | 112 | 8ETFO | 8TRRS | 0.93 |
| 79 | 8TRDA | 8ELSA | 0.91 | 113 | 8ETFO | 8TRTR | 0.93 |
| 80 | 8TRDA | 8IDPP | 0.95 | 114 | 8ETCR | 8ETMK | 0.96 |
| 81 | 8TRDA | 8CLSA | 0.93 | 115 | 8ETCR | 8SGPR | 0.96 |
| 82 | 8TRDA | 8ELLE | 0.97 | 116 | 8ETCR | 8ETLA | 0.98 |
| 83 | 8TRDA | 8DNJU | 0.95 | 117 | 8ETCR | 8ETFO | 1.00 |
| 84 | 8TRDA | 8DNGR | 0.97 | 118 | 8ETCR | 8TRRS | 0.93 |
| 85 | 8TRDA | 8ETMK | 0.91 | 119 | 8ETCR | 8TRTR | 0.93 |
| 86 | 8TRDA | 8TRRS | 0.98 | 120 | 8TRRS | 8WTFW | 0.93 |
| 87 | 8TRDA | 8TRTR | 0.97 | 121 | 8TRRS | 8WTGP | 0.95 |
| 88 | 8ETMK | 8ELLE | 0.91 | 122 | 8TRRS | 8IDPP | 0.93 |
| 89 | 8ETMK | 8TRDA | 0.91 | 123 | 8TRRS | 8ELLE | 0.95 |
| 90 | 8ETMK | 8SGPR | 0.98 | 124 | 8TRRS | 8DNGR | 0.93 |
| 91 | 8ETMK | 8ETLA | 0.97 | 125 | 8TRRS | 8TRDA | 0.98 |
| 92 | 8ETMK | 8ETFO | 0.96 | 126 | 8TRRS | 8ETMK | 0.94 |
| 93 | 8ETMK | 8ETCR | 0.96 | 127 | 8TRRS | 8SGPR | 0.93 |
| 94 | 8ETMK | 8TRRS | 0.94 | 128 | 8TRRS | 8ETLA | 0.92 |
| 95 | 8ETMK | 8TRTR | 0.94 | 129 | 8TRRS | 8ETFO | 0.93 |
| 96 | 8SGPR | 8ETMK | 0.98 | 130 | 8TRRS | 8ETCR | 0.93 |
| 97 | 8SGPR | 8ETLA | 0.96 | 131 | 8TRRS | 8TRTR | 0.99 |
| 98 | 8SGPR | 8ETFO | 0.96 | 132 | 8TRRS | 8TROA | 0.93 |
| 99 | 8SGPR | 8ETCR | 0.96 | 133 | 8TRTR | 8WTFW | 0.92 |
| 100 | 8SGPR | 8TRRS | 0.93 | 134 | 8TRTR | 8WTGP | 0.94 |
| 101 | 8SGPR | 8TRTR | 0.93 | 135 | 8TRTR | 8ELLE | 0.93 |
| 102 | 8ETLA | 8ETMK | 0.97 | 136 | 8TRTR | 8DNGR | 0.92 |

Table 5.4 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) |
|---|---|---|---|---|---|---|---|
| 137 | 8TRTR | 8TRDA | 0.97 | 171 | 8TRCR | 8TRMI | 1.00 |
| 138 | 8TRTR | 8ETMK | 0.94 | 172 | 8TRCR | 8TRRI | 0.99 |
| 139 | 8TRTR | 8SGPR | 0.93 | 173 | 8TRCR | 8TRRO | 0.97 |
| 140 | 8TRTR | 8ETLA | 0.92 | 174 | 8TRCR | 8TRGB | 0.96 |
| 141 | 8TRTR | 8ETFO | 0.93 | 175 | 8TRMI | 8TROA | 0.99 |
| 142 | 8TRTR | 8ETCR | 0.93 | 176 | 8TRMI | 8TRCR | 1.00 |
| 143 | 8TRTR | 8TRRS | 0.99 | 177 | 8TRMI | 8TRRI | 0.99 |
| 144 | 8TRTR | 8TROA | 0.94 | 178 | 8TRMI | 8TRRO | 0.97 |
| 145 | 8CEKE | 8KGKA | 0.95 | 179 | 8TRMI | 8TRGB | 0.96 |
| 146 | 8CEKE | 8CEMA | 0.98 | 180 | 8TRRI | 8TROA | 0.97 |
| 147 | 8KGKA | 8CEKE | 0.95 | 181 | 8TRRI | 8TRCR | 0.99 |
| 148 | 8KGKA | 8CEMA | 0.99 | 182 | 8TRRI | 8TRMI | 0.99 |
| 149 | 8CEMA | 8CEKE | 0.98 | 183 | 8TRRI | 8TRRO | 0.99 |
| 150 | 8CEMA | 8KGKA | 0.99 | 184 | 8TRRI | 8TRGB | 0.98 |
| 151 | 8RIDA | 8RIRI | 0.98 | 185 | 8TRRO | 8TROA | 0.94 |
| 152 | 8RIDA | 8RIFA | 0.95 | 186 | 8TRRO | 8TRCR | 0.97 |
| 153 | 8RIRI | 8RIDA | 0.98 | 187 | 8TRRO | 8TRMI | 0.97 |
| 154 | 8RIRI | 8RIFA | 0.97 | 188 | 8TRRO | 8TRRI | 0.99 |
| 155 | 8WABA | 8CHCO | 0.98 | 189 | 8TRRO | 8TRGB | 1.00 |
| 156 | 8WABA | 8RIFA | 0.94 | 190 | 8TRGB | 8TROA | 0.93 |
| 157 | 8CHCO | 8WABA | 0.98 | 191 | 8TRGB | 8TRCR | 0.96 |
| 158 | 8CHCO | 8RIFA | 0.96 | 192 | 8TRGB | 8TRMI | 0.96 |
| 159 | 8RIFA | 8RIDA | 0.95 | 193 | 8TRGB | 8TRRI | 0.98 |
| 160 | 8RIFA | 8RIRI | 0.97 | 194 | 8TRGB | 8TRRO | 1.00 |
| 161 | 8RIFA | 8WABA | 0.94 | | | | |
| 162 | 8RIFA | 8CHCO | 0.96 | | | | |
| 163 | 8TROA | 8TRRS | 0.93 | | | | |
| 164 | 8TROA | 8TRTR | 0.94 | | | | |
| 165 | 8TROA | 8TRCR | 0.99 | | | | |
| 166 | 8TROA | 8TRMI | 0.99 | | | | |
| 167 | 8TROA | 8TRRI | 0.97 | | | | |
| 168 | 8TROA | 8TRRO | 0.94 | | | | |
| 169 | 8TROA | 8TRGB | 0.93 | | | | |
| 170 | 8TRCR | 8TROA | 0.99 | | | | |

## 5.2 Drainage Area Ratio Method

### 5.2.1 Optimization of Correction Factors and Exponents

The linear regression equations in the form of Equation 2.10 are derived from 358 pairs in the four river basins. These linear regression equations can be considered the best linear relationships, obtained from the relationship between two time series such as flow sequences. Thus, the goal of general linear transfer methods is to find more similar values like B in the Equation 2.10. It is assumed that a slope in the regression equation is equal to the drainage area ratio with correction factor and exponent like Equation 2.11. The representative correction factors K and exponents $\phi$ for the four river basins are developed by the GRG optimization algorithm with the objective function like the equation 2.12 based on the equation 2.11 using Microsoft Excel. Table 5.5 lists the slopes (B) and coefficients of determination ($R^2$) of the regression equations, derived from linear relationships of each pair. Table 5.6 lists the optimized correction factors (K), and exponents ($\phi$) of the equation 2.12 for the four river basins.

### 5.2.2 Comparative Evaluation of the Method Performances

Monthly naturalized flow sequences at gauged sites treated as target ungauged sites are developed based on naturalized flows at other gauged sites treated as source sites for each period-of-analysis in the four WAMs by both methods, DAR method without correction factor and exponent ("the conventional method") and DAR method with correction factor and exponent made by the suggested method in this research ("the suggested method"). The performance of the suggested method is evaluated with NSE between the naturalized flow and synthesized flow. The method performance is also compared with the performance of the conventional method to assess how much or how well the suggested method enhances the performance than the conventional method. Most of all, this section focuses on the performance of the suggested method when a pair DAR is less than 0.3 or more than 1.5.

Table 5.5 Slopes and Coefficients of Determination ($R^2$) of Linear Regression Equations from the WAM dataset in the River Basins

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| Sabine | | | | |
| 1 | SRWP | SRMN | 0.577 | 0.95 |
| 2 | SRMN | SRWP | 1.681 | 0.95 |
| 3 | SRMN | LFQT | 2.071 | 0.84 |
| 4 | SRMN | SRGW | 0.500 | 0.89 |
| 5 | LFQT | SRMN | 0.432 | 0.85 |
| 6 | SRGW | SRMN | 1.851 | 0.88 |
| 7 | SRGW | SRBE | 0.775 | 0.93 |
| 8 | SRGW | SRLP | 0.579 | 0.87 |
| 9 | SRBE | SRGW | 1.232 | 0.92 |
| 10 | SRBE | SRLP | 0.754 | 0.96 |
| 11 | MCTT | MBGR | 1.130 | 0.97 |
| 12 | MBGR | MCTT | 0.867 | 0.97 |
| 13 | SRLP | SRGW | 1.582 | 0.85 |
| 14 | SRLP | SRBE | 1.297 | 0.96 |
| 15 | SRLP | SRBU | 0.582 | 0.83 |
| 16 | SRBU | SRLP | 1.547 | 0.82 |
| 17 | SRBU | SRRL | 0.748 | 0.95 |
| 18 | SRBU | SRSL | 0.708 | 0.95 |
| 19 | SRBW | SRRL | 0.850 | 0.97 |
| 20 | SRBW | SRSL | 0.805 | 0.97 |
| 21 | SRRL | SRBU | 1.303 | 0.95 |
| 22 | SRRL | SRBW | 1.160 | 0.97 |
| 23 | SRRL | SRSL | 0.947 | 1.00 |
| 24 | SRSL | SRBU | 1.371 | 0.94 |
| 25 | SRSL | SRBW | 1.222 | 0.97 |
| 26 | SRSL | SRRL | 1.054 | 1.00 |
| Neches | | | | |
| 27 | KIBR | NEPA | 0.307 | 0.93 |
| 28 | KIBR | NENE | 0.208 | 0.93 |
| 29 | NEPA | KIBR | 3.119 | 0.93 |
| 30 | NEPA | NENE | 0.672 | 0.97 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 31 | NEPA | NEAL | 0.419 | 0.86 |
| 32 | NENE | KIBR | 4.582 | 0.93 |
| 33 | NENE | NEPA | 1.458 | 0.97 |
| 34 | NENE | NEAL | 0.628 | 0.91 |
| 35 | NEAL | NEPA | 2.174 | 0.86 |
| 36 | NEAL | NENE | 1.505 | 0.91 |
| 37 | NEAL | NEDI | 0.691 | 0.94 |
| 38 | NEDI | NEAL | 1.398 | 0.94 |
| 39 | NEDI | NERO | 0.680 | 0.96 |
| 40 | NEDI | NEBA | 0.205 | 0.85 |
| 41 | NEDI | NESL | 0.199 | 0.84 |
| 42 | NERO | NEDI | 1.438 | 0.96 |
| 43 | NERO | ANSR | 0.863 | 0.88 |
| 44 | NERO | NETB | 0.435 | 0.96 |
| 45 | NERO | NEEV | 0.403 | 0.95 |
| 46 | NERO | NEBA | 0.305 | 0.92 |
| 47 | NERO | NESL | 0.295 | 0.91 |
| 48 | MUJA | ANAL | 0.292 | 0.89 |
| 49 | MUJA | ANLU | 0.223 | 0.86 |
| 50 | EFACU | ANAL | 0.125 | 0.87 |
| 51 | EFACU | ANLU | 0.097 | 0.88 |
| 52 | ANAL | MUJA | 3.196 | 0.89 |
| 53 | ANAL | ANLU | 0.767 | 0.99 |
| 54 | ANAL | ANSR | 0.323 | 0.86 |
| 55 | ANAL | NETB | 0.158 | 0.84 |
| 56 | ANAL | NEEV | 0.146 | 0.83 |
| 57 | ANLU | NEAL | 0.966 | 0.85 |
| 58 | ANLU | NEDI | 0.687 | 0.88 |
| 59 | ANLU | MUJA | 4.114 | 0.86 |
| 60 | ANLU | EFACU | 9.620 | 0.88 |
| 61 | ANLU | ANAL | 1.295 | 0.99 |
| 62 | ANLU | ANSR | 0.425 | 0.90 |
| 63 | ANLU | NETB | 0.208 | 0.88 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 64 | ANLU | NEEV | 0.192 | 0.86 |
| 65 | ATCH | AYSA | 4.192 | 0.85 |
| 66 | ATCH | ANSR | 0.160 | 0.87 |
| 67 | AYSA | ATCH | 0.216 | 0.85 |
| 68 | AYSA | ANSR | 0.036 | 0.87 |
| 69 | ANSR | NEDI | 1.550 | 0.85 |
| 70 | ANSR | NERO | 1.077 | 0.88 |
| 71 | ANSR | ANAL | 2.837 | 0.86 |
| 72 | ANSR | ANLU | 2.211 | 0.90 |
| 73 | ANSR | ATCH | 5.761 | 0.87 |
| 74 | ANSR | AYSA | 25.317 | 0.87 |
| 75 | ANSR | NETB | 0.488 | 0.97 |
| 76 | ANSR | NEEV | 0.451 | 0.96 |
| 77 | ANSR | NEBA | 0.340 | 0.92 |
| 78 | ANSR | NESL | 0.329 | 0.91 |
| 79 | NETB | NEDI | 3.211 | 0.91 |
| 80 | NETB | NERO | 2.238 | 0.96 |
| 81 | NETB | ANAL | 5.738 | 0.84 |
| 82 | NETB | ANLU | 4.469 | 0.88 |
| 83 | NETB | ANSR | 2.012 | 0.97 |
| 84 | NETB | NEEV | 0.927 | 0.99 |
| 85 | NETB | NEBA | 0.701 | 0.96 |
| 86 | NETB | NESL | 0.679 | 0.96 |
| 87 | NEEV | NEDI | 3.448 | 0.90 |
| 88 | NEEV | NERO | 2.407 | 0.95 |
| 89 | NEEV | ANAL | 6.145 | 0.83 |
| 90 | NEEV | ANLU | 4.787 | 0.86 |
| 91 | NEEV | ANSR | 2.157 | 0.96 |
| 92 | NEEV | NEBA | 0.758 | 0.97 |
| 93 | NEEV | NESL | 0.734 | 0.97 |
| 94 | NEBA | NEDI | 4.442 | 0.85 |
| 95 | NEBA | NERO | 3.117 | 0.92 |
| 96 | NEBA | ANSR | 2.788 | 0.92 |
| 97 | NEBA | NETB | 1.394 | 0.96 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 98 | NEBA | NEEV | 1.299 | 0.97 |
| 99 | NEBA | NESL | 0.969 | 1.00 |
| 100 | NESL | NEDI | 4.573 | 0.84 |
| 101 | NESL | NERO | 3.211 | 0.91 |
| 102 | NESL | ANSR | 2.871 | 0.91 |
| 103 | NESL | NETB | 1.436 | 0.96 |
| 104 | NESL | NEEV | 1.338 | 0.97 |
| 105 | NESL | NEBA | 1.032 | 1.00 |
| GSA | | | | |
| 106 | CP02 | CP01 | 1.490 | 0.82 |
| 107 | CP01 | CP02 | 0.583 | 0.82 |
| 108 | CP03 | CP02 | 1.033 | 0.99 |
| 109 | CP04 | CP02 | 1.181 | 0.96 |
| 110 | CP06 | CP02 | 1.363 | 0.89 |
| 111 | CP02 | CP03 | 0.958 | 0.99 |
| 112 | CP04 | CP03 | 1.147 | 0.98 |
| 113 | CP06 | CP03 | 1.343 | 0.92 |
| 114 | CP02 | CP04 | 0.823 | 0.96 |
| 115 | CP03 | CP04 | 0.863 | 0.98 |
| 116 | CP06 | CP04 | 1.182 | 0.95 |
| 117 | CP02 | CP06 | 0.623 | 0.89 |
| 118 | CP03 | CP06 | 0.663 | 0.92 |
| 119 | CP04 | CP06 | 0.775 | 0.95 |
| 120 | CP09 | CP08 | 1.042 | 0.98 |
| 121 | CP10 | CP08 | 2.236 | 0.83 |
| 122 | CP08 | CP09 | 0.945 | 0.98 |
| 123 | CP10 | CP09 | 2.123 | 0.86 |
| 124 | CP08 | CP10 | 0.393 | 0.83 |
| 125 | CP09 | CP10 | 0.412 | 0.86 |
| 126 | CP15 | CP14 | 1.044 | 0.99 |
| 127 | CP38 | CP14 | 1.597 | 0.89 |
| 128 | CPEST | CP14 | 1.645 | 0.88 |
| 129 | CP14 | CP15 | 0.955 | 0.99 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 130 | CP38 | CP15 | 1.534 | 0.91 |
| 131 | CPEST | CP15 | 1.581 | 0.89 |
| 132 | CP27 | CP21 | 1.118 | 0.89 |
| 133 | CP28 | CP21 | 1.198 | 0.84 |
| 134 | CP27 | CP23 | 1.182 | 0.89 |
| 135 | CP28 | CP23 | 1.265 | 0.84 |
| 136 | CP261 | CP25 | 0.907 | 0.98 |
| 137 | CP262 | CP25 | 0.423 | 0.98 |
| 138 | CP263 | CP25 | 0.176 | 0.98 |
| 139 | CP25 | CP261 | 1.087 | 0.98 |
| 140 | CP25 | CP262 | 2.333 | 0.98 |
| 141 | CP21 | CP27 | 0.818 | 0.89 |
| 142 | CP23 | CP27 | 0.772 | 0.89 |
| 143 | CP28 | CP27 | 1.084 | 0.98 |
| 144 | CP29 | CP27 | 1.439 | 0.88 |
| 145 | CP32 | CP27 | 1.583 | 0.84 |
| 146 | CP21 | CP28 | 0.735 | 0.84 |
| 147 | CP23 | CP28 | 0.693 | 0.84 |
| 148 | CP27 | CP28 | 0.909 | 0.98 |
| 149 | CP29 | CP28 | 1.337 | 0.91 |
| 150 | CP32 | CP28 | 1.475 | 0.88 |
| 151 | CP27 | CP29 | 0.630 | 0.88 |
| 152 | CP28 | CP29 | 0.697 | 0.91 |
| 153 | CP32 | CP29 | 1.105 | 0.97 |
| 154 | CP27 | CP32 | 0.556 | 0.84 |
| 155 | CP28 | CP32 | 0.617 | 0.88 |
| 156 | CP29 | CP32 | 0.886 | 0.97 |
| 157 | CP38 | CP37 | 3.302 | 0.86 |
| 158 | CPEST | CP37 | 3.404 | 0.85 |
| 159 | CP14 | CP38 | 0.585 | 0.89 |
| 160 | CP15 | CP38 | 0.615 | 0.91 |
| 161 | CP37 | CP38 | 0.271 | 0.86 |
| 162 | CP14 | CPEST | 0.563 | 0.88 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 162 | CP14 | CPEST | 0.563 | 0.88 |
| 163 | CP15 | CPEST | 0.591 | 0.89 |
| Trinity | | | | |
| 164 | 8WTJA | 8WTBO | 0.353 | 0.86 |
| 165 | 8BSBR | 8WTBO | 0.243 | 0.87 |
| 166 | 8WTBO | 8WTJA | 2.468 | 0.86 |
| 167 | 8WTBO | 8BSBR | 3.664 | 0.87 |
| 168 | 8WTBO | 8WTFW | 0.568 | 0.94 |
| 169 | 8WTBO | 8WTGP | 0.459 | 0.91 |
| 170 | 8WTBO | 8DNJU | 2.854 | 0.88 |
| 171 | 8WTBO | 8DNGR | 1.476 | 0.85 |
| 172 | 8WTBO | 8TRDA | 0.171 | 0.85 |
| 173 | 8CTAL | 8CTBE | 0.470 | 0.95 |
| 174 | 8CTAL | 8CTFW | 0.354 | 0.94 |
| 175 | 8CTBE | 8CTAL | 2.041 | 0.95 |
| 176 | 8CTBE | 8CTFW | 0.754 | 0.99 |
| 177 | 8CTFW | 8CTAL | 2.684 | 0.94 |
| 178 | 8CTFW | 8CTBE | 1.131 | 0.99 |
| 179 | 8WTFW | 8WTBO | 1.666 | 0.94 |
| 180 | 8WTFW | 8WTGP | 0.813 | 0.98 |
| 181 | 8WTFW | 8DNJU | 4.871 | 0.88 |
| 182 | 8WTFW | 8DNGR | 2.557 | 0.88 |
| 183 | 8WTFW | 8TRDA | 0.303 | 0.92 |
| 184 | 8WTFW | 8TRRS | 0.208 | 0.86 |
| 185 | 8WTFW | 8TRTR | 0.195 | 0.85 |
| 186 | 8WTGP | 8WTBO | 2.001 | 0.91 |
| 187 | 8WTGP | 8WTFW | 1.209 | 0.98 |
| 188 | 8WTGP | 8DNJU | 5.869 | 0.85 |
| 189 | 8WTGP | 8DNGR | 3.101 | 0.87 |
| 190 | 8WTGP | 8TRDA | 0.373 | 0.94 |
| 191 | 8WTGP | 8TRRS | 0.258 | 0.90 |
| 192 | 8WTGP | 8TRTR | 0.242 | 0.88 |
| 193 | 8ELSA | 8IDPP | 1.316 | 0.84 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 194 | 8ELSA | 8CLSA | 1.791 | 0.96 |
| 195 | 8ELSA | 8ELLE | 0.235 | 0.85 |
| 196 | 8ELSA | 8DNJU | 1.542 | 0.89 |
| 197 | 8ELSA | 8DNGR | 0.804 | 0.87 |
| 198 | 8ELSA | 8TRDA | 0.091 | 0.83 |
| 199 | 8IDPP | 8ELSA | 0.656 | 0.84 |
| 200 | 8IDPP | 8CLSA | 1.198 | 0.84 |
| 201 | 8IDPP | 8ELLE | 0.175 | 0.97 |
| 202 | 8IDPP | 8DNGR | 0.565 | 0.87 |
| 203 | 8IDPP | 8TRDA | 0.067 | 0.90 |
| 204 | 8IDPP | 8TRRS | 0.046 | 0.86 |
| 205 | 8CLSA | 8ELSA | 0.540 | 0.96 |
| 206 | 8CLSA | 8IDPP | 0.724 | 0.84 |
| 207 | 8CLSA | 8ELLE | 0.131 | 0.88 |
| 208 | 8CLSA | 8DNJU | 0.865 | 0.94 |
| 209 | 8CLSA | 8DNGR | 0.449 | 0.91 |
| 210 | 8CLSA | 8TRDA | 0.051 | 0.87 |
| 211 | 8ELLE | 8ELSA | 3.702 | 0.85 |
| 212 | 8ELLE | 8IDPP | 5.543 | 0.97 |
| 213 | 8ELLE | 8CLSA | 6.829 | 0.88 |
| 214 | 8ELLE | 8DNJU | 6.061 | 0.88 |
| 215 | 8ELLE | 8DNGR | 3.235 | 0.91 |
| 216 | 8ELLE | 8TRDA | 0.381 | 0.94 |
| 217 | 8ELLE | 8ETMK | 6.052 | 0.83 |
| 218 | 8ELLE | 8TRRS | 0.265 | 0.90 |
| 219 | 8ELLE | 8TRTR | 0.247 | 0.87 |
| 220 | 8DNJU | 8WTBO | 0.315 | 0.88 |
| 221 | 8DNJU | 8WTFW | 0.183 | 0.88 |
| 222 | 8DNJU | 8WTGP | 0.149 | 0.85 |
| 223 | 8DNJU | 8ELSA | 0.587 | 0.89 |
| 224 | 8DNJU | 8CLSA | 1.094 | 0.94 |
| 225 | 8DNJU | 8ELLE | 0.147 | 0.88 |
| 226 | 8DNJU | 8DNGR | 0.515 | 0.96 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 227 | 8DNJU | 8TRDA | 0.058 | 0.90 |
| 228 | 8DNGR | 8WTBO | 0.592 | 0.85 |
| 229 | 8DNGR | 8WTFW | 0.350 | 0.88 |
| 230 | 8DNGR | 8WTGP | 0.285 | 0.87 |
| 231 | 8DNGR | 8ELSA | 1.112 | 0.87 |
| 232 | 8DNGR | 8IDPP | 1.567 | 0.87 |
| 233 | 8DNGR | 8CLSA | 2.061 | 0.91 |
| 234 | 8DNGR | 8ELLE | 0.284 | 0.91 |
| 235 | 8DNGR | 8DNJU | 1.871 | 0.96 |
| 236 | 8DNGR | 8TRDA | 0.112 | 0.93 |
| 237 | 8DNGR | 8TRRS | 0.077 | 0.87 |
| 238 | 8DNGR | 8TRTR | 0.072 | 0.84 |
| 239 | 8TRDA | 8WTBO | 5.101 | 0.85 |
| 240 | 8TRDA | 8WTFW | 3.081 | 0.92 |
| 241 | 8TRDA | 8WTGP | 2.549 | 0.94 |
| 242 | 8TRDA | 8ELSA | 9.399 | 0.83 |
| 243 | 8TRDA | 8IDPP | 13.769 | 0.90 |
| 244 | 8TRDA | 8CLSA | 17.462 | 0.87 |
| 245 | 8TRDA | 8ELLE | 2.487 | 0.94 |
| 246 | 8TRDA | 8DNJU | 15.683 | 0.90 |
| 247 | 8TRDA | 8DNGR | 8.355 | 0.93 |
| 248 | 8TRDA | 8ETMK | 15.457 | 0.83 |
| 249 | 8TRDA | 8TRRS | 0.696 | 0.97 |
| 250 | 8TRDA | 8TRTR | 0.651 | 0.94 |
| 251 | 8ETMK | 8ELLE | 0.144 | 0.83 |
| 252 | 8ETMK | 8TRDA | 0.056 | 0.83 |
| 253 | 8ETMK | 8SGPR | 1.686 | 0.96 |
| 254 | 8ETMK | 8ETLA | 0.265 | 0.94 |
| 255 | 8ETMK | 8ETFO | 0.175 | 0.93 |
| 256 | 8ETMK | 8ETCR | 0.159 | 0.92 |
| 257 | 8ETMK | 8TRRS | 0.041 | 0.88 |
| 258 | 8ETMK | 8TRTR | 0.038 | 0.87 |
| 259 | 8SGPR | 8ETMK | 0.577 | 0.96 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 260 | 8SGPR | 8ETLA | 0.155 | 0.93 |
| 261 | 8SGPR | 8ETFO | 0.102 | 0.93 |
| 262 | 8SGPR | 8ETCR | 0.093 | 0.92 |
| 263 | 8SGPR | 8TRRS | 0.024 | 0.87 |
| 264 | 8SGPR | 8TRTR | 0.022 | 0.86 |
| 265 | 8ETLA | 8ETMK | 3.592 | 0.94 |
| 266 | 8ETLA | 8SGPR | 6.120 | 0.93 |
| 267 | 8ETLA | 8ETFO | 0.653 | 0.97 |
| 268 | 8ETLA | 8ETCR | 0.596 | 0.96 |
| 269 | 8ETLA | 8TRRS | 0.148 | 0.85 |
| 270 | 8ETLA | 8TRTR | 0.139 | 0.85 |
| 271 | 8ETFO | 8ETMK | 5.402 | 0.93 |
| 272 | 8ETFO | 8SGPR | 9.246 | 0.93 |
| 273 | 8ETFO | 8ETLA | 1.492 | 0.97 |
| 274 | 8ETFO | 8ETCR | 0.914 | 0.99 |
| 275 | 8ETFO | 8TRRS | 0.225 | 0.87 |
| 276 | 8ETFO | 8TRTR | 0.213 | 0.87 |
| 277 | 8ETCR | 8ETMK | 5.874 | 0.92 |
| 278 | 8ETCR | 8SGPR | 10.066 | 0.92 |
| 279 | 8ETCR | 8ETLA | 1.622 | 0.96 |
| 280 | 8ETCR | 8ETFO | 1.088 | 0.99 |
| 281 | 8ETCR | 8TRRS | 0.245 | 0.87 |
| 282 | 8ETCR | 8TRTR | 0.233 | 0.87 |
| 283 | 8TRRS | 8WTFW | 4.240 | 0.86 |
| 284 | 8TRRS | 8WTGP | 3.533 | 0.90 |
| 285 | 8TRRS | 8IDPP | 19.118 | 0.86 |
| 286 | 8TRRS | 8ELLE | 3.460 | 0.90 |
| 287 | 8TRRS | 8DNGR | 11.436 | 0.87 |
| 288 | 8TRRS | 8TRDA | 1.395 | 0.97 |
| 289 | 8TRRS | 8ETMK | 22.391 | 0.88 |
| 290 | 8TRRS | 8SGPR | 38.035 | 0.87 |
| 291 | 8TRRS | 8ETLA | 6.007 | 0.85 |
| 292 | 8TRRS | 8ETFO | 3.996 | 0.87 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 293 | 8TRRS | 8ETCR | 3.663 | 0.87 |
| 294 | 8TRRS | 8TRTR | 0.940 | 0.99 |
| 295 | 8TRRS | 8TROA | 0.611 | 0.86 |
| 296 | 8TRTR | 8WTFW | 4.447 | 0.85 |
| 297 | 8TRTR | 8WTGP | 3.716 | 0.88 |
| 298 | 8TRTR | 8ELLE | 3.609 | 0.87 |
| 299 | 8TRTR | 8DNGR | 11.949 | 0.84 |
| 300 | 8TRTR | 8TRDA | 1.460 | 0.94 |
| 301 | 8TRTR | 8ETMK | 23.593 | 0.87 |
| 302 | 8TRTR | 8SGPR | 40.149 | 0.86 |
| 303 | 8TRTR | 8ETLA | 6.341 | 0.85 |
| 304 | 8TRTR | 8ETFO | 4.233 | 0.87 |
| 305 | 8TRTR | 8ETCR | 3.884 | 0.87 |
| 306 | 8TRTR | 8TRRS | 1.052 | 0.99 |
| 307 | 8TRTR | 8TROA | 0.655 | 0.89 |
| 308 | 8CEKE | 8KGKA | 0.696 | 0.90 |
| 309 | 8CEKE | 8CEMA | 0.301 | 0.96 |
| 310 | 8KGKA | 8CEKE | 1.332 | 0.90 |
| 311 | 8KGKA | 8CEMA | 0.418 | 0.97 |
| 312 | 8CEMA | 8CEKE | 3.228 | 0.96 |
| 313 | 8CEMA | 8KGKA | 2.343 | 0.97 |
| 314 | 8RIDA | 8RIRI | 0.447 | 0.96 |
| 315 | 8RIDA | 8RIFA | 0.185 | 0.90 |
| 316 | 8RIRI | 8RIDA | 2.166 | 0.96 |
| 317 | 8RIRI | 8RIFA | 0.411 | 0.94 |
| 318 | 8WABA | 8CHCO | 0.209 | 0.96 |
| 319 | 8WABA | 8RIFA | 0.095 | 0.87 |
| 320 | 8CHCO | 8WABA | 4.647 | 0.96 |
| 321 | 8CHCO | 8RIFA | 0.456 | 0.92 |
| 322 | 8RIFA | 8RIDA | 4.979 | 0.90 |
| 323 | 8RIFA | 8RIRI | 2.290 | 0.94 |
| 324 | 8RIFA | 8WABA | 9.572 | 0.87 |
| 325 | 8RIFA | 8CHCO | 2.067 | 0.92 |

Table 5.5 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Slope (Y=BX) | Coefficient of Deter. ($R^2$) |
|---|---|---|---|---|
| 326 | 8TROA | 8TRRS | 1.468 | 0.86 |
| 327 | 8TROA | 8TRTR | 1.407 | 0.89 |
| 328 | 8TROA | 8TRCR | 0.916 | 0.97 |
| 329 | 8TROA | 8TRMI | 0.876 | 0.97 |
| 330 | 8TROA | 8TRRI | 0.804 | 0.94 |
| 331 | 8TROA | 8TRRO | 0.726 | 0.89 |
| 332 | 8TROA | 8TRGB | 0.668 | 0.86 |
| 333 | 8TRCR | 8TROA | 1.068 | 0.97 |
| 334 | 8TRCR | 8TRMI | 0.953 | 1.00 |
| 335 | 8TRCR | 8TRRI | 0.881 | 0.99 |
| 336 | 8TRCR | 8TRRO | 0.799 | 0.94 |
| 337 | 8TRCR | 8TRGB | 0.736 | 0.92 |
| 338 | 8TRMI | 8TROA | 1.120 | 0.97 |
| 339 | 8TRMI | 8TRCR | 1.045 | 1.00 |
| 340 | 8TRMI | 8TRRI | 0.923 | 0.99 |
| 341 | 8TRMI | 8TRRO | 0.839 | 0.95 |
| 342 | 8TRMI | 8TRGB | 0.772 | 0.92 |
| 343 | 8TRRI | 8TROA | 1.195 | 0.94 |
| 344 | 8TRRI | 8TRCR | 1.124 | 0.99 |
| 345 | 8TRRI | 8TRMI | 1.073 | 0.99 |
| 346 | 8TRRI | 8TRRO | 0.913 | 0.97 |
| 347 | 8TRRI | 8TRGB | 0.843 | 0.95 |
| 348 | 8TRRO | 8TROA | 1.273 | 0.89 |
| 349 | 8TRRO | 8TRCR | 1.202 | 0.94 |
| 350 | 8TRRO | 8TRMI | 1.150 | 0.95 |
| 351 | 8TRRO | 8TRRI | 1.076 | 0.97 |
| 352 | 8TRRO | 8TRGB | 0.926 | 0.99 |
| 353 | 8TRGB | 8TROA | 1.359 | 0.86 |
| 354 | 8TRGB | 8TRCR | 1.285 | 0.92 |
| 355 | 8TRGB | 8TRMI | 1.228 | 0.92 |
| 356 | 8TRGB | 8TRRI | 1.153 | 0.95 |
| 357 | 8TRGB | 8TRRO | 1.074 | 0.99 |

Table 5.6 Optimized Representative Correction Factors (K) and Exponents (ϕ) for the Four WAMs

| Basin | Correction factors (K) | Exponents (ϕ) |
|---|---|---|
| Sabine | 0.958 | 0.974 |
| Neches | 0.961 | 0.983 |
| GSA | 0.922 | 0.890 |
| Trinity | 0.885 | 0.902 |

The selected pairs are 357 pairs in total from the four WAM datasets, and these pairs have a varying range of drainage area ratios. The Sabine WAM has are 5 pairs that have DARs, less than 0.3 or more than 1.5, the Neches WAM has 43 pairs, the GSA WAM has 18 pairs, and the Trinity WAM has 113 pairs, respectively. These pairs from WAMs have 179 pairs in total that have less than 0.3 or more than 1.5 of DAR, and these account for 50.1 percent of the total selected pairs.

The evaluation of both method performances for the Sabine WAM is summarized in Table 5.7. The maximum DAR is 2.32, and the minimum DAR is 0.43 among 26 pairs in total. The average NSE is 0.92 in the conventional method, and 0.92 in the suggested method, respectively. The minimum NSE of conventional method is 0.79 from the pair, control points SRLP and SRBU, and the suggested method is 0.81 from the same pair. Both methods, however, show the same performances in the cases of the 5 pairs mentioned above.

Table 5.8 summarizes the performance of both methods for the Neches WAM. The 79 pairs in total have DAR 38.79 in maximum, and DAR 0.03 in minimum. The average NSEs of both methods are 0.88 in total 79 pairs. However, the average NSE of the conventional method is 0.84, and the average NSE of the suggested method is 0.85 in the 43 pairs mentioned above. The minimum NSE of conventional method is 0.43 from the pair ANSR and AYSA that has maximum DAR. The suggested method has 0.64 NSE from the same pair. The transfer performance is significantly improved from 0.43 to 0.64 at the same pair.

Table 5.7 Comparative Evaluation of Performances by Both Methods for the Sabine WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 1 | SRWP | SRMN | 0.56 | 0.95 | 0.95 |
| 2 | SRMN | SRWP | 1.79 | 0.95 | 0.95 |
| 3 | SRMN | LFQT | 2.32 | 0.84 | 0.84 |
| 4 | SRMN | SRGW | 0.49 | 0.88 | 0.89 |
| 5 | LFQT | SRMN | 0.43 | 0.84 | 0.84 |
| 6 | SRGW | SRMN | 2.06 | 0.88 | 0.88 |
| 7 | SRGW | SRBE | 0.78 | 0.92 | 0.93 |
| 8 | SRGW | SRLP | 0.58 | 0.84 | 0.86 |
| 9 | SRBE | SRGW | 1.29 | 0.92 | 0.92 |
| 10 | SRBE | SRLP | 0.74 | 0.95 | 0.96 |
| 11 | MCTT | MBGR | 1.10 | 0.92 | 0.95 |
| 12 | MBGR | MCTT | 0.91 | 0.89 | 0.92 |
| 13 | SRLP | SRGW | 1.73 | 0.85 | 0.85 |
| 14 | SRLP | SRBE | 1.35 | 0.95 | 0.96 |
| 15 | SRLP | SRBU | 0.65 | 0.79 | 0.81 |
| 16 | SRBU | SRLP | 1.55 | 0.82 | 0.82 |
| 17 | SRBU | SRRL | 0.80 | 0.95 | 0.95 |
| 18 | SRBU | SRSL | 0.77 | 0.94 | 0.95 |
| 19 | SRBW | SRRL | 0.88 | 0.97 | 0.97 |
| 20 | SRBW | SRSL | 0.84 | 0.97 | 0.97 |
| 21 | SRRL | SRBU | 1.25 | 0.94 | 0.93 |
| 22 | SRRL | SRBW | 1.13 | 0.97 | 0.95 |
| 23 | SRRL | SRSL | 0.96 | 1.00 | 0.99 |
| 24 | SRSL | SRBU | 1.30 | 0.93 | 0.91 |
| 25 | SRSL | SRBW | 1.19 | 0.96 | 0.94 |
| 26 | SRSL | SRRL | 1.05 | 0.99 | 0.98 |

Table 5.8 Comparative Evaluation of Performances by Both Methods for the Neches WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 1 | KIBR | NEPA | 0.28 | 0.92 | 0.91 |
| 2 | KIBR | NENE | 0.20 | 0.93 | 0.92 |
| 3 | NEPA | KIBR | 3.61 | 0.89 | 0.92 |
| 4 | NEPA | NENE | 0.73 | 0.96 | 0.96 |
| 5 | NEPA | NEAL | 0.43 | 0.85 | 0.86 |
| 6 | NENE | KIBR | 4.94 | 0.91 | 0.92 |
| 7 | NENE | NEPA | 1.37 | 0.96 | 0.95 |
| 8 | NENE | NEAL | 0.59 | 0.90 | 0.90 |
| 9 | NEAL | NEPA | 2.32 | 0.84 | 0.84 |
| 10 | NEAL | NENE | 1.70 | 0.88 | 0.90 |
| 11 | NEAL | NEDI | 0.71 | 0.94 | 0.94 |
| 12 | NEDI | NEAL | 1.40 | 0.94 | 0.94 |
| 13 | NEDI | NERO | 0.75 | 0.94 | 0.95 |
| 14 | NEDI | NEBA | 0.28 | 0.66 | 0.68 |
| 15 | NEDI | NESL | 0.27 | 0.63 | 0.66 |
| 16 | NERO | NEDI | 1.33 | 0.95 | 0.94 |
| 17 | NERO | ANSR | 1.05 | 0.81 | 0.84 |
| 18 | NERO | NETB | 0.48 | 0.94 | 0.95 |
| 19 | NERO | NEEV | 0.46 | 0.92 | 0.93 |
| 20 | NERO | NEBA | 0.37 | 0.85 | 0.86 |
| 21 | NERO | NESL | 0.36 | 0.83 | 0.85 |
| 22 | MUJA | ANAL | 0.30 | 0.89 | 0.89 |
| 23 | MUJA | ANLU | 0.23 | 0.86 | 0.86 |
| 24 | EFACU | ANAL | 0.12 | 0.87 | 0.87 |
| 25 | EFACU | ANLU | 0.10 | 0.88 | 0.88 |
| 26 | ANAL | MUJA | 3.39 | 0.88 | 0.89 |
| 27 | ANAL | ANLU | 0.80 | 0.99 | 0.99 |
| 28 | ANAL | ANSR | 0.37 | 0.82 | 0.83 |
| 29 | ANAL | NETB | 0.17 | 0.84 | 0.84 |
| 30 | ANAL | NEEV | 0.16 | 0.81 | 0.81 |
| 31 | ANLU | NEAL | 0.82 | 0.81 | 0.80 |
| 32 | ANLU | NEDI | 0.59 | 0.85 | 0.84 |
| 33 | ANLU | MUJA | 4.26 | 0.86 | 0.86 |
| 34 | ANLU | EFACU | 10.20 | 0.88 | 0.88 |

Table 5.8 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 35 | ANLU | ANAL | 1.26 | 0.99 | 0.98 |
| 36 | ANLU | ANSR | 0.46 | 0.88 | 0.89 |
| 37 | ANLU | NETB | 0.21 | 0.88 | 0.88 |
| 38 | ANLU | NEEV | 0.20 | 0.86 | 0.86 |
| 39 | ATCH | AYSA | 5.66 | 0.65 | 0.74 |
| 40 | ATCH | ANSR | 0.15 | 0.86 | 0.86 |
| 41 | AYSA | ATCH | 0.18 | 0.80 | 0.80 |
| 42 | AYSA | ANSR | 0.03 | 0.75 | 0.76 |
| 43 | ANSR | NEDI | 1.27 | 0.80 | 0.78 |
| 44 | ANSR | NERO | 0.95 | 0.86 | 0.85 |
| 45 | ANSR | ANAL | 2.71 | 0.86 | 0.85 |
| 46 | ANSR | ANLU | 2.16 | 0.90 | 0.89 |
| 47 | ANSR | ATCH | 6.85 | 0.81 | 0.85 |
| 48 | ANSR | AYSA | 38.79 | 0.43 | 0.64 |
| 49 | ANSR | NETB | 0.46 | 0.96 | 0.96 |
| 50 | ANSR | NEEV | 0.44 | 0.95 | 0.95 |
| 51 | ANSR | NEBA | 0.35 | 0.91 | 0.91 |
| 52 | ANSR | NESL | 0.34 | 0.90 | 0.91 |
| 53 | NETB | NEDI | 2.78 | 0.88 | 0.85 |
| 54 | NETB | NERO | 2.09 | 0.94 | 0.93 |
| 55 | NETB | ANAL | 5.95 | 0.84 | 0.84 |
| 56 | NETB | ANLU | 4.73 | 0.87 | 0.88 |
| 57 | NETB | ANSR | 2.19 | 0.95 | 0.97 |
| 58 | NETB | NEEV | 0.96 | 0.99 | 0.99 |
| 59 | NETB | NEBA | 0.77 | 0.94 | 0.95 |
| 60 | NETB | NESL | 0.76 | 0.93 | 0.95 |
| 61 | NEEV | NEDI | 2.89 | 0.85 | 0.82 |
| 62 | NEEV | NERO | 2.17 | 0.93 | 0.91 |
| 63 | NEEV | ANAL | 6.19 | 0.82 | 0.81 |
| 64 | NEEV | ANLU | 4.93 | 0.86 | 0.85 |
| 65 | NEEV | ANSR | 2.28 | 0.94 | 0.95 |
| 66 | NEEV | NEBA | 0.80 | 0.97 | 0.97 |
| 67 | NEEV | NESL | 0.79 | 0.96 | 0.97 |
| 68 | NEBA | NEDI | 3.61 | 0.78 | 0.75 |

Table 5.8 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 69 | NEBA | NERO | 2.71 | 0.88 | 0.85 |
| 70 | NEBA | ANSR | 2.85 | 0.91 | 0.90 |
| 71 | NEBA | NETB | 1.30 | 0.95 | 0.94 |
| 72 | NEBA | NEEV | 1.25 | 0.97 | 0.96 |
| 73 | NEBA | NESL | 0.98 | 1.00 | 1.00 |
| 74 | NESL | NEDI | 3.68 | 0.77 | 0.73 |
| 75 | NESL | NERO | 2.76 | 0.87 | 0.84 |
| 76 | NESL | ANSR | 2.90 | 0.90 | 0.90 |
| 77 | NESL | NETB | 1.32 | 0.94 | 0.93 |
| 78 | NESL | NEEV | 1.27 | 0.96 | 0.95 |
| 79 | NESL | NEBA | 1.02 | 1.00 | 1.00 |

The performance of both methods, described by NSE for the GSA WAM is tabulated in Table 5.9. The 58 pairs in total have a pair with DAR 2.59 in maximum and a pair with DAR 0.21 in minimum. The performance of the conventional method has NSE 0.83 in average, and the suggested method as NSE 0.85 in average. The average NSEs of both methods in the 18 pairs mentioned above are different from the averages in total 58 pairs. The conventional method has NSE 0.74 in average, and the suggested method has NSE 0.78 in average. The lowest performance is NSE 0.22 from the pair CP28 and CP21 by the conventional method and NSE 0.58 from the same pair by the suggested method, respectively. The transfer performance is tremendously enhanced from 0.22 to 0.58 at the same pair. In addition, the suggested method improves the performance from 0.42 to 0.68 at the pair CP28 and CP23.

Table 5.9 Comparative Evaluation of Performances by Both Methods for the GSA WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 1 | CP02 | CP01 | 1.57 | 0.81 | 0.80 |
| 2 | CP01 | CP02 | 0.64 | 0.81 | 0.82 |
| 3 | CP03 | CP02 | 1.09 | 0.98 | 0.98 |
| 4 | CP04 | CP02 | 1.16 | 0.96 | 0.94 |
| 5 | CP06 | CP02 | 1.60 | 0.55 | 0.61 |
| 6 | CP02 | CP03 | 0.92 | 0.98 | 0.97 |
| 7 | CP04 | CP03 | 1.06 | 0.97 | 0.95 |
| 8 | CP06 | CP03 | 1.47 | 0.70 | 0.71 |
| 9 | CP02 | CP04 | 0.87 | 0.96 | 0.96 |
| 10 | CP03 | CP04 | 0.94 | 0.97 | 0.98 |
| 11 | CP06 | CP04 | 1.38 | 0.72 | 0.78 |
| 12 | CP02 | CP06 | 0.63 | 0.78 | 0.78 |
| 13 | CP03 | CP06 | 0.68 | 0.83 | 0.83 |
| 14 | CP04 | CP06 | 0.72 | 0.86 | 0.85 |
| 15 | CP09 | CP08 | 1.16 | 0.96 | 0.98 |
| 16 | CP10 | CP08 | 2.36 | 0.77 | 0.76 |
| 17 | CP08 | CP09 | 0.86 | 0.96 | 0.95 |
| 18 | CP10 | CP09 | 2.04 | 0.76 | 0.71 |
| 19 | CP08 | CP10 | 0.42 | 0.81 | 0.81 |
| 20 | CP09 | CP10 | 0.49 | 0.78 | 0.78 |
| 21 | CP15 | CP14 | 1.05 | 0.99 | 0.99 |
| 22 | CP38 | CP14 | 2.05 | 0.77 | 0.88 |
| 23 | CPEST | CP14 | 2.05 | 0.78 | 0.87 |
| 24 | CP14 | CP15 | 0.95 | 0.99 | 0.98 |
| 25 | CP38 | CP15 | 1.95 | 0.79 | 0.89 |
| 26 | CPEST | CP15 | 1.95 | 0.81 | 0.89 |
| 27 | CP27 | CP21 | 1.52 | 0.73 | 0.84 |
| 28 | CP28 | CP21 | 2.07 | 0.22 | 0.58 |
| 29 | CP27 | CP23 | 1.48 | 0.81 | 0.87 |
| 30 | CP28 | CP23 | 2.02 | 0.42 | 0.68 |
| 31 | CP261 | CP25 | 1.03 | 0.96 | 0.98 |
| 32 | CP262 | CP25 | 0.48 | 0.96 | 0.96 |
| 33 | CP263 | CP25 | 0.21 | 0.95 | 0.88 |
| 34 | CP25 | CP261 | 0.97 | 0.97 | 0.95 |

Table 5.9 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 35 | CP25 | CP262 | 2.07 | 0.97 | 0.91 |
| 36 | CP21 | CP27 | 0.66 | 0.84 | 0.82 |
| 37 | CP23 | CP27 | 0.68 | 0.87 | 0.86 |
| 38 | CP28 | CP27 | 1.36 | 0.89 | 0.96 |
| 39 | CP29 | CP27 | 1.81 | 0.78 | 0.85 |
| 40 | CP32 | CP27 | 2.19 | 0.63 | 0.78 |
| 41 | CP21 | CP28 | 0.48 | 0.70 | 0.70 |
| 42 | CP23 | CP28 | 0.50 | 0.75 | 0.75 |
| 43 | CP27 | CP28 | 0.73 | 0.93 | 0.91 |
| 44 | CP29 | CP28 | 1.33 | 0.90 | 0.88 |
| 45 | CP32 | CP28 | 1.61 | 0.86 | 0.86 |
| 46 | CP27 | CP29 | 0.55 | 0.86 | 0.85 |
| 47 | CP28 | CP29 | 0.75 | 0.90 | 0.91 |
| 48 | CP32 | CP29 | 1.21 | 0.95 | 0.97 |
| 49 | CP27 | CP32 | 0.46 | 0.80 | 0.81 |
| 50 | CP28 | CP32 | 0.62 | 0.88 | 0.88 |
| 51 | CP29 | CP32 | 0.82 | 0.96 | 0.95 |
| 52 | CP38 | CP37 | 2.59 | 0.76 | 0.65 |
| 53 | CPEST | CP37 | 2.59 | 0.73 | 0.62 |
| 54 | CP14 | CP38 | 0.49 | 0.85 | 0.85 |
| 55 | CP15 | CP38 | 0.51 | 0.86 | 0.86 |
| 56 | CP37 | CP38 | 0.39 | 0.63 | 0.59 |
| 57 | CP14 | CPEST | 0.49 | 0.85 | 0.85 |
| 58 | CP15 | CPEST | 0.51 | 0.86 | 0.86 |

Table 5.10 summarizes the performance of both methods for the Trinity WAM. Maximum DAR is 75.56, and minimum DAR is 0.01 in total 194 pairs. The average NSE is 0.77 by the conventional method and 0.84 by the suggested method, respectively. The performance of the suggested method is apparently superior to the conventional method. The performances of both methods in the 113 pairs mentioned above show more obvious

differences. The average NSE by the conventional method is 0.70, and the average NSE by the suggested method is 0.81. The suggested method leads to acceptable NSEs from all the 113 pairs, while the conventional method results in unacceptable NSEs (negative values) in the 5 pairs out of the 113 pairs. In other words, the suggested method obviously enhances the performances from unacceptable to acceptable levels in the 5 pairs. The minimum performances are -0.49 by the conventional method, 0.40 by the suggested method, respectively. In addition, the suggested method enhances the transfer performances in 71 pairs out of the 113 pairs that have less than 0.3 or more than 1.5 of DAR.

As the results of the evaluation of performances, the conventional method leads to 24 unsatisfied (below 0.5 of NSE) performances and 5 unacceptable(negative value of NSE) performances, but the suggested method results in only 2 unsatisfied performances out of total 357 pairs.

## 5.3 Regional Statistical Method

### 5.3.1 Regional Statistical Parameters

The mean or standard deviation of annual or monthly flows is significantly related to the basin or climatic variables (Benson and Matalas, 1967). Benson and Matalas (1967) suggested the general form of the equation as:

$$\mathrm{Y} = \mathrm{a}A^{b_1}S^{b_2}{S_t}^{b_3}P^{b_4}{S_n}^{b_5}F^{b_6} \tag{5.1}$$

Where, Y is the dependent variable, and A, $S$, $S_t$, P, $S_n$, and F are the basin or climatic variables. a is the regression constant, and the b values are the regression coefficients.

The statistical parameters such as mean and variance of naturalized flow dataset should be highly related to basin area because of its homogeneity or statistic stationarity. Based upon this assumption, linear regressions equations could be derived from logarithmic relationship between statistical parameters and only basin areas.

Table 5.10 Comparative Evaluation of Performances by Both Methods for the Trinity WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 1 | 8WTJA | 8WTBO | 0.40 | 0.84 | 0.85 |
| 2 | 8BSBR | 8WTBO | 0.19 | 0.83 | 0.84 |
| 3 | 8WTBO | 8WTJA | 2.53 | 0.85 | 0.82 |
| 4 | 8WTBO | 8BSBR | 5.18 | 0.69 | 0.87 |
| 5 | 8WTBO | 8WTFW | 0.66 | 0.91 | 0.93 |
| 6 | 8WTBO | 8WTGP | 0.56 | 0.85 | 0.88 |
| 7 | 8WTBO | 8DNJU | 4.31 | 0.60 | 0.85 |
| 8 | 8WTBO | 8DNGR | 2.45 | 0.40 | 0.73 |
| 9 | 8WTBO | 8TRDA | 0.28 | 0.41 | 0.41 |
| 10 | 8CTAL | 8CTBE | 0.58 | 0.88 | 0.92 |
| 11 | 8CTAL | 8CTFW | 0.48 | 0.78 | 0.83 |
| 12 | 8CTBE | 8CTAL | 1.72 | 0.92 | 0.85 |
| 13 | 8CTBE | 8CTFW | 0.83 | 0.97 | 0.99 |
| 14 | 8CTFW | 8CTAL | 2.06 | 0.87 | 0.78 |
| 15 | 8CTFW | 8CTBE | 1.20 | 0.98 | 0.93 |
| 16 | 8WTFW | 8WTBO | 1.52 | 0.93 | 0.88 |
| 17 | 8WTFW | 8WTGP | 0.85 | 0.97 | 0.97 |
| 18 | 8WTFW | 8DNJU | 6.54 | 0.74 | 0.87 |
| 19 | 8WTFW | 8DNGR | 3.71 | 0.65 | 0.85 |
| 20 | 8WTFW | 8TRDA | 0.43 | 0.72 | 0.77 |
| 21 | 8WTFW | 8TRRS | 0.32 | 0.54 | 0.56 |
| 22 | 8WTFW | 8TRTR | 0.31 | 0.49 | 0.50 |
| 23 | 8WTGP | 8WTBO | 1.78 | 0.88 | 0.82 |
| 24 | 8WTGP | 8WTFW | 1.17 | 0.98 | 0.95 |
| 25 | 8WTGP | 8DNJU | 7.66 | 0.73 | 0.83 |
| 26 | 8WTGP | 8DNGR | 4.35 | 0.67 | 0.85 |
| 27 | 8WTGP | 8TRDA | 0.50 | 0.79 | 0.85 |
| 28 | 8WTGP | 8TRRS | 0.38 | 0.64 | 0.68 |
| 29 | 8WTGP | 8TRTR | 0.36 | 0.61 | 0.64 |
| 30 | 8ELSA | 8IDPP | 1.43 | 0.83 | 0.83 |
| 31 | 8ELSA | 8CLSA | 1.29 | 0.87 | 0.79 |
| 32 | 8ELSA | 8ELLE | 0.23 | 0.84 | 0.84 |
| 33 | 8ELSA | 8DNJU | 0.95 | 0.72 | 0.66 |
| 34 | 8ELSA | 8DNGR | 0.54 | 0.75 | 0.72 |

Table 5.10 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 35 | 8ELSA | 8TRDA | 0.06 | 0.72 | 0.78 |
| 36 | 8IDPP | 8ELSA | 0.70 | 0.82 | 0.83 |
| 37 | 8IDPP | 8CLSA | 0.90 | 0.76 | 0.71 |
| 38 | 8IDPP | 8ELLE | 0.16 | 0.95 | 0.96 |
| 39 | 8IDPP | 8DNGR | 0.38 | 0.73 | 0.72 |
| 40 | 8IDPP | 8TRDA | 0.04 | 0.76 | 0.84 |
| 41 | 8IDPP | 8TRRS | 0.03 | 0.76 | 0.83 |
| 42 | 8CLSA | 8ELSA | 0.77 | 0.74 | 0.85 |
| 43 | 8CLSA | 8IDPP | 1.11 | 0.54 | 0.71 |
| 44 | 8CLSA | 8ELLE | 0.18 | 0.73 | 0.68 |
| 45 | 8CLSA | 8DNJU | 0.74 | 0.91 | 0.88 |
| 46 | 8CLSA | 8DNGR | 0.42 | 0.90 | 0.90 |
| 47 | 8CLSA | 8TRDA | 0.05 | 0.87 | 0.85 |
| 48 | 8ELLE | 8ELSA | 4.39 | 0.80 | 0.83 |
| 49 | 8ELLE | 8IDPP | 6.29 | 0.94 | 0.93 |
| 50 | 8ELLE | 8CLSA | 5.67 | 0.83 | 0.70 |
| 51 | 8ELLE | 8DNJU | 4.18 | 0.75 | 0.61 |
| 52 | 8ELLE | 8DNGR | 2.37 | 0.81 | 0.71 |
| 53 | 8ELLE | 8TRDA | 0.27 | 0.84 | 0.84 |
| 54 | 8ELLE | 8ETMK | 8.81 | 0.61 | 0.83 |
| 55 | 8ELLE | 8TRRS | 0.21 | 0.83 | 0.85 |
| 56 | 8ELLE | 8TRTR | 0.20 | 0.81 | 0.83 |
| 57 | 8DNJU | 8WTBO | 0.23 | 0.81 | 0.81 |
| 58 | 8DNJU | 8WTFW | 0.15 | 0.84 | 0.86 |
| 59 | 8DNJU | 8WTGP | 0.13 | 0.83 | 0.84 |
| 60 | 8DNJU | 8ELSA | 1.05 | 0.22 | 0.53 |
| 61 | 8DNJU | 8CLSA | 1.36 | 0.87 | 0.93 |
| 62 | 8DNJU | 8ELLE | 0.24 | 0.44 | 0.40 |
| 63 | 8DNJU | 8DNGR | 0.57 | 0.95 | 0.96 |
| 64 | 8DNJU | 8TRDA | 0.07 | 0.88 | 0.79 |
| 65 | 8DNGR | 8WTBO | 0.41 | 0.75 | 0.73 |
| 66 | 8DNGR | 8WTFW | 0.27 | 0.82 | 0.82 |
| 67 | 8DNGR | 8WTGP | 0.23 | 0.82 | 0.83 |
| 68 | 8DNGR | 8ELSA | 1.85 | 0.40 | 0.71 |

Table 5.10 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 69 | 8DNGR | 8IDPP | 2.65 | 0.35 | 0.72 |
| 70 | 8DNGR | 8CLSA | 2.39 | 0.88 | 0.91 |
| 71 | 8DNGR | 8ELLE | 0.42 | 0.64 | 0.70 |
| 72 | 8DNGR | 8DNJU | 1.76 | 0.95 | 0.90 |
| 73 | 8DNGR | 8TRDA | 0.12 | 0.93 | 0.91 |
| 74 | 8DNGR | 8TRRS | 0.09 | 0.83 | 0.78 |
| 75 | 8DNGR | 8TRTR | 0.08 | 0.80 | 0.73 |
| 76 | 8TRDA | 8WTBO | 3.54 | 0.73 | 0.60 |
| 77 | 8TRDA | 8WTFW | 2.33 | 0.84 | 0.73 |
| 78 | 8TRDA | 8WTGP | 1.99 | 0.88 | 0.78 |
| 79 | 8TRDA | 8ELSA | 16.03 | 0.26 | 0.79 |
| 80 | 8TRDA | 8IDPP | 22.95 | 0.36 | 0.89 |
| 81 | 8TRDA | 8CLSA | 20.70 | 0.82 | 0.80 |
| 82 | 8TRDA | 8ELLE | 3.65 | 0.66 | 0.91 |
| 83 | 8TRDA | 8DNJU | 15.27 | 0.88 | 0.75 |
| 84 | 8TRDA | 8DNGR | 8.66 | 0.92 | 0.84 |
| 85 | 8TRDA | 8ETMK | 32.14 | -0.49 | 0.72 |
| 86 | 8TRDA | 8TRRS | 0.75 | 0.95 | 0.96 |
| 87 | 8TRDA | 8TRTR | 0.72 | 0.92 | 0.94 |
| 88 | 8ETMK | 8ELLE | 0.11 | 0.78 | 0.81 |
| 89 | 8ETMK | 8TRDA | 0.03 | 0.59 | 0.71 |
| 90 | 8ETMK | 8SGPR | 1.68 | 0.96 | 0.93 |
| 91 | 8ETMK | 8ETLA | 0.25 | 0.93 | 0.93 |
| 92 | 8ETMK | 8ETFO | 0.17 | 0.92 | 0.92 |
| 93 | 8ETMK | 8ETCR | 0.15 | 0.91 | 0.91 |
| 94 | 8ETMK | 8TRRS | 0.02 | 0.66 | 0.79 |
| 95 | 8ETMK | 8TRTR | 0.02 | 0.66 | 0.79 |
| 96 | 8SGPR | 8ETMK | 0.59 | 0.96 | 0.96 |
| 97 | 8SGPR | 8ETLA | 0.15 | 0.92 | 0.93 |
| 98 | 8SGPR | 8ETFO | 0.10 | 0.92 | 0.91 |
| 99 | 8SGPR | 8ETCR | 0.09 | 0.92 | 0.91 |
| 100 | 8SGPR | 8TRRS | 0.01 | 0.65 | 0.81 |
| 101 | 8SGPR | 8TRTR | 0.01 | 0.66 | 0.81 |
| 102 | 8ETLA | 8ETMK | 4.07 | 0.91 | 0.92 |

Table 5.10 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 103 | 8ETLA | 8SGPR | 6.84 | 0.91 | 0.89 |
| 104 | 8ETLA | 8ETFO | 0.69 | 0.96 | 0.96 |
| 105 | 8ETLA | 8ETCR | 0.62 | 0.95 | 0.95 |
| 106 | 8ETLA | 8TRRS | 0.09 | 0.69 | 0.75 |
| 107 | 8ETLA | 8TRTR | 0.09 | 0.69 | 0.75 |
| 108 | 8ETFO | 8ETMK | 5.88 | 0.91 | 0.87 |
| 109 | 8ETFO | 8SGPR | 9.89 | 0.92 | 0.85 |
| 110 | 8ETFO | 8ETLA | 1.45 | 0.96 | 0.92 |
| 111 | 8ETFO | 8ETCR | 0.89 | 0.99 | 0.97 |
| 112 | 8ETFO | 8TRRS | 0.14 | 0.67 | 0.71 |
| 113 | 8ETFO | 8TRTR | 0.13 | 0.68 | 0.72 |
| 114 | 8ETCR | 8ETMK | 6.61 | 0.89 | 0.87 |
| 115 | 8ETCR | 8SGPR | 11.12 | 0.90 | 0.85 |
| 116 | 8ETCR | 8ETLA | 1.62 | 0.95 | 0.92 |
| 117 | 8ETCR | 8ETFO | 1.12 | 0.99 | 0.98 |
| 118 | 8ETCR | 8TRRS | 0.15 | 0.69 | 0.72 |
| 119 | 8ETCR | 8TRTR | 0.15 | 0.69 | 0.73 |
| 120 | 8TRRS | 8WTFW | 3.12 | 0.75 | 0.62 |
| 121 | 8TRRS | 8WTGP | 2.66 | 0.80 | 0.68 |
| 122 | 8TRRS | 8IDPP | 30.62 | 0.40 | 0.84 |
| 123 | 8TRRS | 8ELLE | 4.87 | 0.67 | 0.88 |
| 124 | 8TRRS | 8DNGR | 11.55 | 0.83 | 0.72 |
| 125 | 8TRRS | 8TRDA | 1.33 | 0.96 | 0.92 |
| 126 | 8TRRS | 8ETMK | 42.87 | -0.18 | 0.84 |
| 127 | 8TRRS | 8SGPR | 72.09 | -0.14 | 0.85 |
| 128 | 8TRRS | 8ETLA | 10.54 | 0.15 | 0.78 |
| 129 | 8TRRS | 8ETFO | 7.29 | 0.02 | 0.72 |
| 130 | 8TRRS | 8ETCR | 6.49 | 0.12 | 0.74 |
| 131 | 8TRRS | 8TRTR | 0.95 | 0.98 | 0.97 |
| 132 | 8TRRS | 8TROA | 0.63 | 0.85 | 0.86 |
| 133 | 8TRTR | 8WTFW | 3.27 | 0.73 | 0.60 |
| 134 | 8TRTR | 8WTGP | 2.79 | 0.78 | 0.66 |
| 135 | 8TRTR | 8ELLE | 5.10 | 0.63 | 0.84 |
| 136 | 8TRTR | 8DNGR | 12.11 | 0.80 | 0.69 |

Table 5.10 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 137 | 8TRTR | 8TRDA | 1.40 | 0.93 | 0.89 |
| 138 | 8TRTR | 8ETMK | 44.94 | -0.18 | 0.83 |
| 139 | 8TRTR | 8SGPR | 75.56 | -0.13 | 0.84 |
| 140 | 8TRTR | 8ETLA | 11.05 | 0.15 | 0.78 |
| 141 | 8TRTR | 8ETFO | 7.64 | 0.04 | 0.74 |
| 142 | 8TRTR | 8ETCR | 6.80 | 0.15 | 0.76 |
| 143 | 8TRTR | 8TRRS | 1.05 | 0.98 | 0.96 |
| 144 | 8TRTR | 8TROA | 0.67 | 0.89 | 0.88 |
| 145 | 8CEKE | 8KGKA | 0.81 | 0.87 | 0.90 |
| 146 | 8CEKE | 8CEMA | 0.26 | 0.93 | 0.94 |
| 147 | 8KGKA | 8CEKE | 1.23 | 0.89 | 0.85 |
| 148 | 8KGKA | 8CEMA | 0.32 | 0.90 | 0.89 |
| 149 | 8CEMA | 8CEKE | 3.88 | 0.91 | 0.95 |
| 150 | 8CEMA | 8KGKA | 3.15 | 0.81 | 0.97 |
| 151 | 8RIDA | 8RIRI | 0.45 | 0.96 | 0.96 |
| 152 | 8RIDA | 8RIFA | 0.17 | 0.89 | 0.89 |
| 153 | 8RIRI | 8RIDA | 2.20 | 0.96 | 0.93 |
| 154 | 8RIRI | 8RIFA | 0.38 | 0.92 | 0.91 |
| 155 | 8WABA | 8CHCO | 0.18 | 0.94 | 0.95 |
| 156 | 8WABA | 8RIFA | 0.09 | 0.88 | 0.87 |
| 157 | 8CHCO | 8WABA | 5.41 | 0.93 | 0.94 |
| 158 | 8CHCO | 8RIFA | 0.49 | 0.92 | 0.92 |
| 159 | 8RIFA | 8RIDA | 5.88 | 0.85 | 0.87 |
| 160 | 8RIFA | 8RIRI | 2.67 | 0.89 | 0.92 |
| 161 | 8RIFA | 8WABA | 10.99 | 0.85 | 0.83 |
| 162 | 8RIFA | 8CHCO | 2.03 | 0.92 | 0.88 |
| 163 | 8TROA | 8TRRS | 1.58 | 0.84 | 0.83 |
| 164 | 8TROA | 8TRTR | 1.50 | 0.88 | 0.87 |
| 165 | 8TROA | 8TRCR | 0.92 | 0.97 | 0.95 |
| 166 | 8TROA | 8TRMI | 0.89 | 0.97 | 0.96 |
| 167 | 8TROA | 8TRRI | 0.82 | 0.94 | 0.93 |
| 168 | 8TROA | 8TRRO | 0.75 | 0.88 | 0.88 |
| 169 | 8TROA | 8TRGB | 0.71 | 0.85 | 0.86 |
| 170 | 8TRCR | 8TROA | 1.08 | 0.97 | 0.95 |

Table 5.10 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Drainage Area Ratio ($A_y/A_x$) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Conventional Method | Suggested Method |
|---|---|---|---|---|---|
| 171 | 8TRCR | 8TRMI | 0.96 | 0.99 | 0.98 |
| 172 | 8TRCR | 8TRRI | 0.89 | 0.98 | 0.97 |
| 173 | 8TRCR | 8TRRO | 0.81 | 0.94 | 0.93 |
| 174 | 8TRCR | 8TRGB | 0.78 | 0.91 | 0.91 |
| 175 | 8TRMI | 8TROA | 1.13 | 0.97 | 0.95 |
| 176 | 8TRMI | 8TRCR | 1.04 | 0.99 | 0.97 |
| 177 | 8TRMI | 8TRRI | 0.93 | 0.98 | 0.97 |
| 178 | 8TRMI | 8TRRO | 0.84 | 0.94 | 0.93 |
| 179 | 8TRMI | 8TRGB | 0.81 | 0.92 | 0.91 |
| 180 | 8TRRI | 8TROA | 1.21 | 0.94 | 0.91 |
| 181 | 8TRRI | 8TRCR | 1.12 | 0.98 | 0.96 |
| 182 | 8TRRI | 8TRMI | 1.08 | 0.98 | 0.96 |
| 183 | 8TRRI | 8TRRO | 0.91 | 0.97 | 0.95 |
| 184 | 8TRRI | 8TRGB | 0.87 | 0.95 | 0.94 |
| 185 | 8TRRO | 8TROA | 1.34 | 0.87 | 0.86 |
| 186 | 8TRRO | 8TRCR | 1.24 | 0.93 | 0.91 |
| 187 | 8TRRO | 8TRMI | 1.19 | 0.94 | 0.92 |
| 188 | 8TRRO | 8TRRI | 1.10 | 0.97 | 0.95 |
| 189 | 8TRRO | 8TRGB | 0.96 | 0.99 | 0.98 |
| 190 | 8TRGB | 8TROA | 1.40 | 0.84 | 0.82 |
| 191 | 8TRGB | 8TRCR | 1.29 | 0.91 | 0.88 |
| 192 | 8TRGB | 8TRMI | 1.24 | 0.91 | 0.89 |
| 193 | 8TRGB | 8TRRI | 1.15 | 0.95 | 0.92 |
| 194 | 8TRGB | 8TRRO | 1.04 | 0.99 | 0.96 |

Figure 5.1 shows the logarithmic relationships between statistical parameters of monthly naturalized flows and watershed areas at the control points in the Sabine River Basin. The coefficients of determination ($R^2$) are 0.9903 for means and 0.9897 for standard deviations, respectively.

The statistic parameters of monthly naturalized flows in the Neches River Basin also have logarithmic relationships with the basin area, as shown in Figure 5.2. The logarithmic relationship between mean and basin area has a $R^2$ value of 0.9843, and the same relationship between standard deviation and basin area has a $R^2$ value of 0.9805.

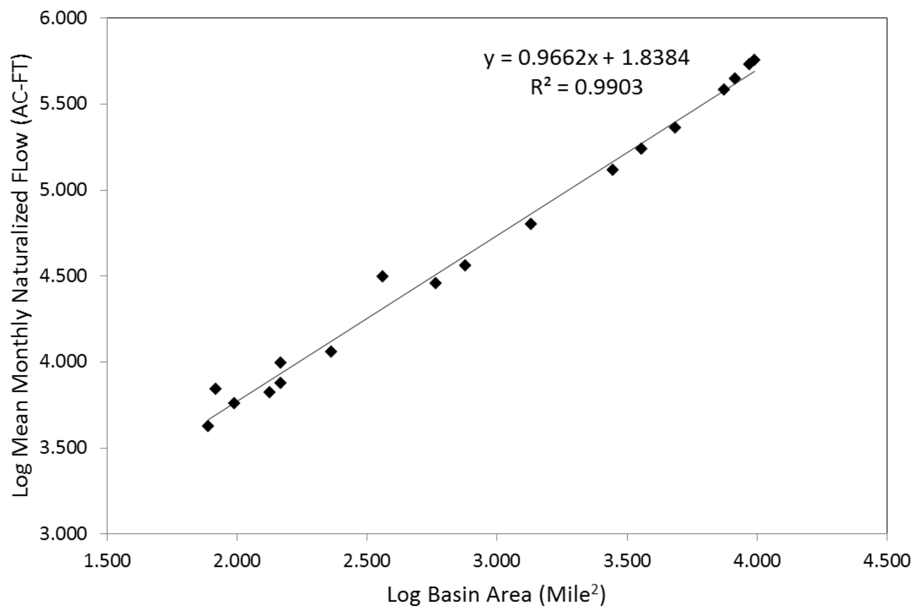
The GSA River Basins have highly linear logarithmic relationships between statistical parameters (mean and standard deviation) and basin area as shown in Figure 5.3. $R^2$ values of each relationship are 0.9413 for mean and 0.9741 for standard deviation, respectively. This shows the relationship between standard deviation and basin area is more linear than the relationship between mean and basin area for the GSA River Basins.

In the Trinity River Basin, Figure 5.4 describes the logarithmic relationships between two statistical parameters, mean and standard deviation and basin area. The linear regression equations have 0.9308 $R^2$ value for mean, and 0.9596 $R^2$ value for standard deviation, respectively.

The regression equations in Figures 5.1 to 5.4 are made based on logarithm variables. These logarithmic equations are converted into algebraic equations, and these are summarized in Table 5.11.

Table 5.11 Algebraic Regression Equations for Regional Statistical Parameters

| WAM | Algebraic Regression Equation (X: Basin Area, Y: Regional Statistical Parameters) | |
|---|---|---|
| | Mean (Y) | Standard Deviation (y) |
| Sabine | $Y=10^{1.8384} X^{0.9662}$ | $y=10^{2.1044} X^{0.9111}$ |
| Neches | $Y=10^{1.7568} X^{0.9735}$ | $y=10^{1.9456} X^{0.9399}$ |
| GSA | $Y=10^{0.6973} X^{1.1628}$ | $y=10^{1.2333} X^{1.0517}$ |
| Trinity | $Y=10^{1.5858} X^{0.9521}$ | $y=10^{2.0403} X^{0.8837}$ |



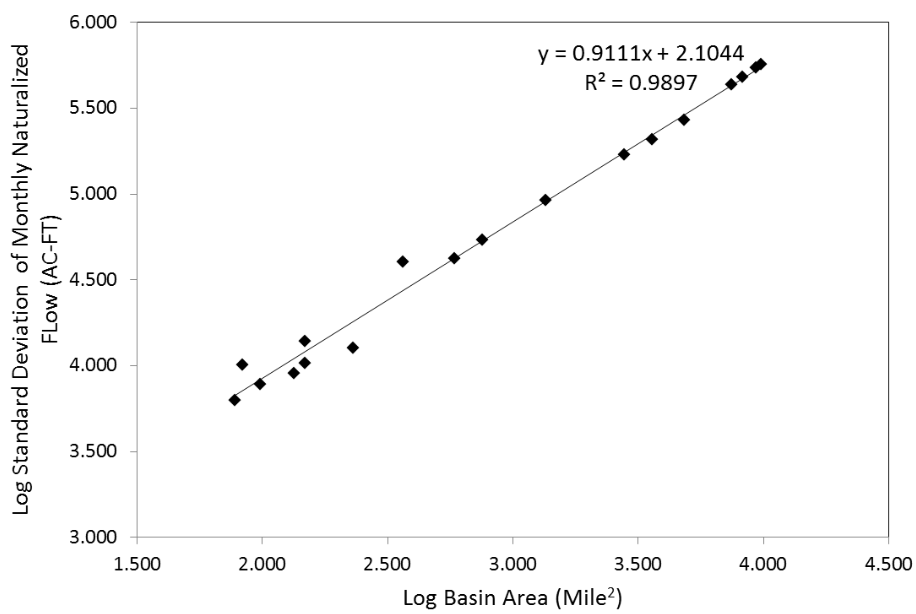
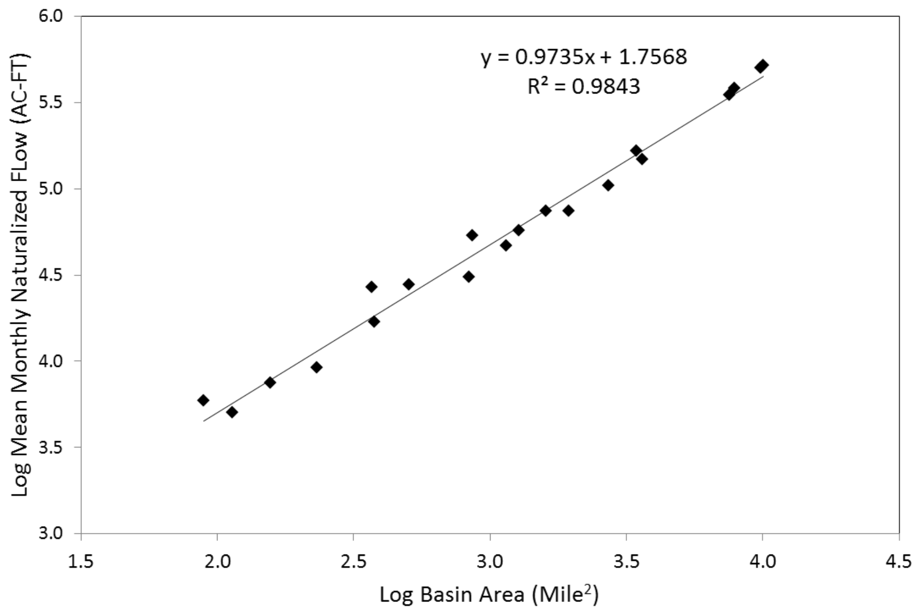




Figure 5.1 Logarithmic Linear Relationship between Mean (above) and Standard Deviation (blow) of Monthly Naturalized Flows and Basin Area for the Sabine River Basin



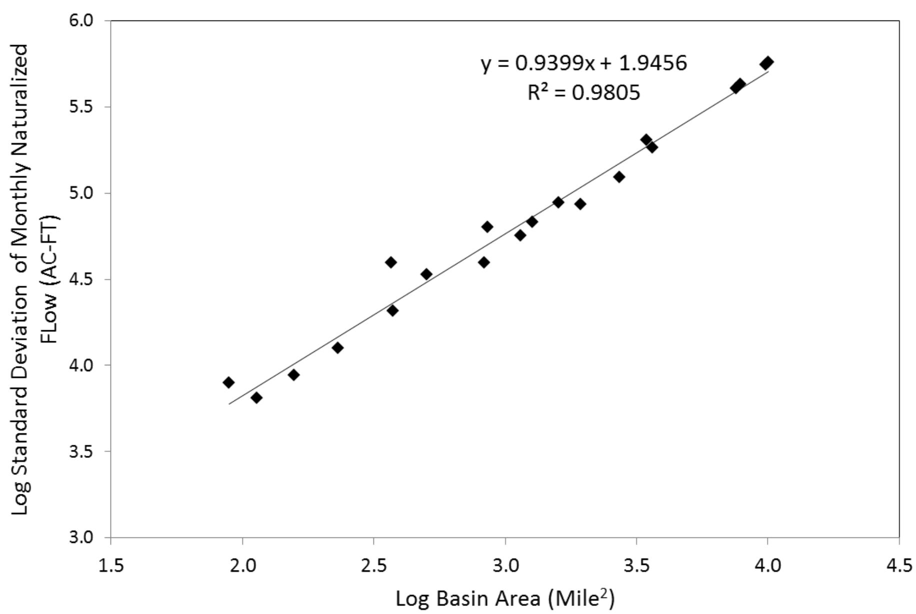
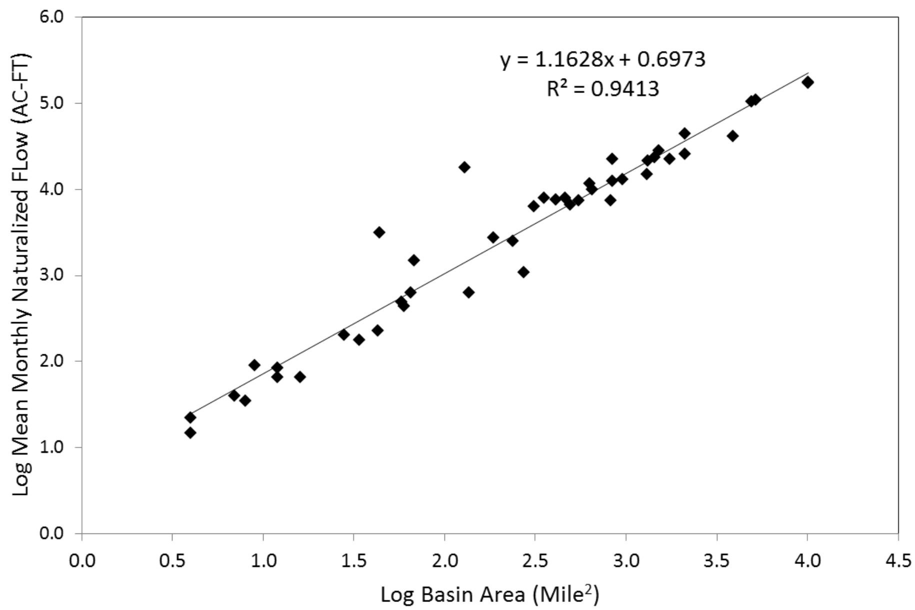




Figure 5.2 Logarithmic Linear Relationship between Mean (above) and Standard Deviation (blow) of Monthly Naturalized Flows and Basin Area for the Neches River Basin



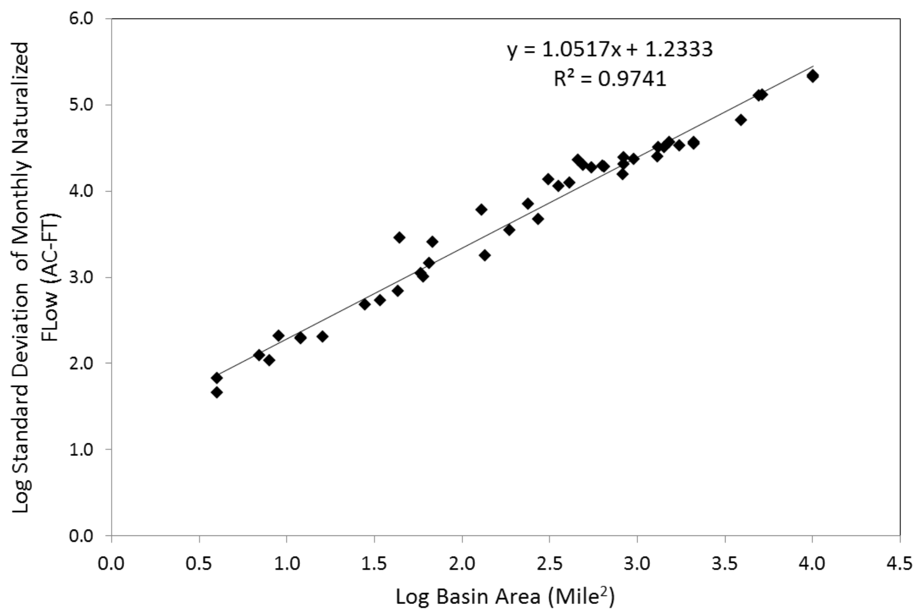
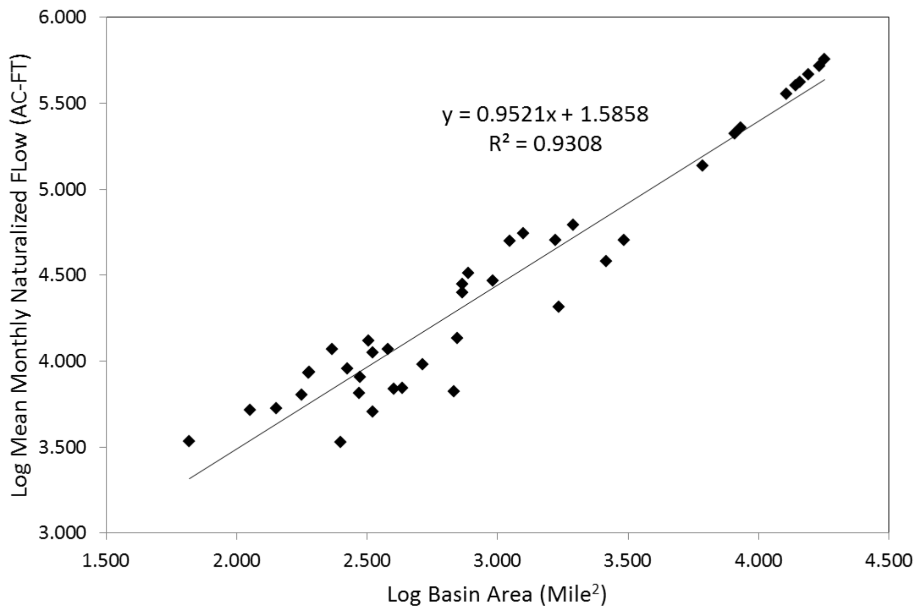




Figure 5.3 Logarithmic Linear Relationship between Mean (above) and Standard Deviation (blow) of Monthly Naturalized Flows and Basin Area for the GSA River Basins



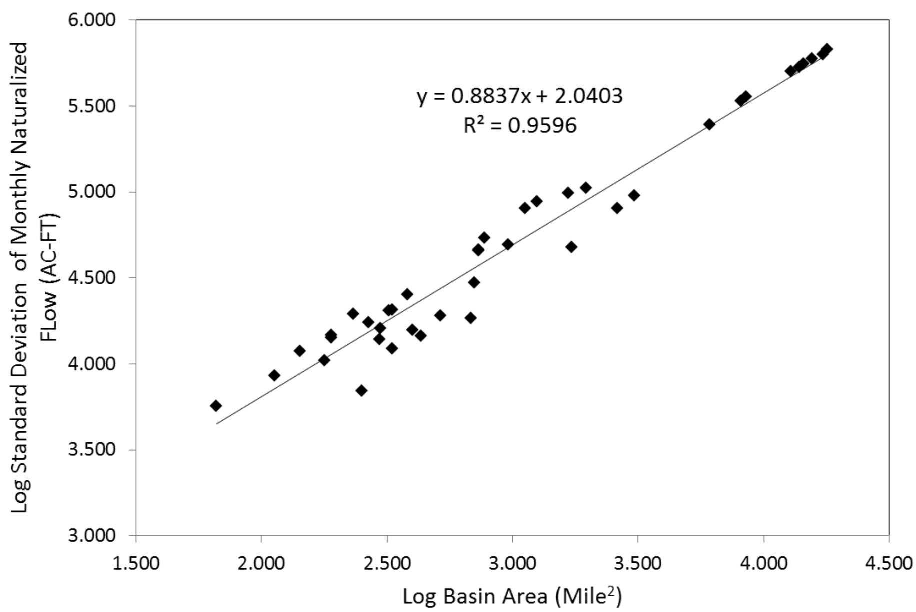




Figure 5.4 Logarithmic Linear Relationship between Mean (above) and Standard Deviation (blow) of Monthly Naturalized Flows and Basin Area for the Trinity River Basin

### 5.3.2 Comparative Evaluation of the Method Performances

Monthly naturalized flow sequences at gauged sites treated as ungauged target sites are synthesized based on naturalized flows at other gauged sites treated as source sites for each period-of-analysis in the four WAMs using Equation 2.13. When Equation 2.13 is used, the first method ("the existing method") uses sample mean and standard deviation from monthly naturalized flow data for m(x) and S(x) and estimated mean and standard deviation from a regional regression equation for m(y) and S(y), but the second method ("the proposed method") uses only estimated mean and standard deviation from a regional regression equation for m(x), m(y), S(y), and S(y). The proposed method is expected to enhance the performance of Equation 2.13 because this may remove expected biases on statistic parameters mentioned in Chapter II. The performances of both methods are evaluated with NSE between the naturalized flows and synthesized flows by two different methods, and both NSEs at same pair are compared for evaluating how much or well the proposed method improves the performance than the existing method.

The performances by the two different methods for the Sabine WAM are tabulated in Table 5.12. The average NSE values are 0.91 for the existing method, and 0.92 for the proposed method. Both methods result in acceptable or satisfied values. The proposed method slightly outperforms the existing method at 21 pairs out of total 26 pairs, but the differences between the two methods are imperceptible.

Table 5.13 summarizes the performances by the two methods for the Neches WAM. The two methods have the same average NSE values, 0.88. There are no unacceptable or unsatisfied performances by the two methods in total 79 pairs like the Sabine WAM. The performances of the existing method are better than the performances of the proposed method at 42 pairs out of total 79 pairs in the Neches WAM. However, the differences between both performances are also marginal like the Sabine WAM.

Table 5.12 Comparative Evaluation of Performances by Both Methods for the Sabine WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 1 | SRWP | SRMN | 0.98 | 0.95 | 0.95 |
| 2 | SRMN | SRWP | 0.98 | 0.94 | 0.95 |
| 3 | SRMN | LFQT | 0.92 | 0.83 | 0.84 |
| 4 | SRMN | SRGW | 0.94 | 0.88 | 0.89 |
| 5 | LFQT | SRMN | 0.92 | 0.83 | 0.84 |
| 6 | SRGW | SRMN | 0.94 | 0.87 | 0.88 |
| 7 | SRGW | SRBE | 0.96 | 0.92 | 0.93 |
| 8 | SRGW | SRLP | 0.93 | 0.85 | 0.86 |
| 9 | SRBE | SRGW | 0.96 | 0.92 | 0.92 |
| 10 | SRBE | SRLP | 0.98 | 0.95 | 0.96 |
| 11 | MCTT | MBGR | 0.98 | 0.93 | 0.97 |
| 12 | MBGR | MCTT | 0.98 | 0.90 | 0.97 |
| 13 | SRLP | SRGW | 0.93 | 0.84 | 0.85 |
| 14 | SRLP | SRBE | 0.98 | 0.95 | 0.96 |
| 15 | SRLP | SRBU | 0.91 | 0.80 | 0.79 |
| 16 | SRBU | SRLP | 0.91 | 0.82 | 0.82 |
| 17 | SRBU | SRRL | 0.98 | 0.96 | 0.94 |
| 18 | SRBU | SRSL | 0.98 | 0.95 | 0.93 |
| 19 | SRBW | SRRL | 0.99 | 0.97 | 0.97 |
| 20 | SRBW | SRSL | 0.98 | 0.97 | 0.96 |
| 21 | SRRL | SRBU | 0.98 | 0.94 | 0.94 |
| 22 | SRRL | SRBW | 0.99 | 0.96 | 0.97 |
| 23 | SRRL | SRSL | 1.00 | 0.98 | 1.00 |
| 24 | SRSL | SRBU | 0.98 | 0.93 | 0.93 |
| 25 | SRSL | SRBW | 0.98 | 0.95 | 0.96 |
| 26 | SRSL | SRRL | 1.00 | 0.98 | 1.00 |

Table 5.13 Comparative Evaluation of Performances by Both Methods for the Neches WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 1 | KIBR | NEPA | 0.97 | 0.86 | 0.93 |
| 2 | KIBR | NENE | 0.96 | 0.85 | 0.93 |
| 3 | NEPA | KIBR | 0.97 | 0.79 | 0.92 |
| 4 | NEPA | NENE | 0.98 | 0.84 | 0.95 |
| 5 | NEPA | NEAL | 0.92 | 0.69 | 0.85 |
| 6 | NENE | KIBR | 0.96 | 0.87 | 0.93 |
| 7 | NENE | NEPA | 0.98 | 0.92 | 0.96 |
| 8 | NENE | NEAL | 0.95 | 0.84 | 0.91 |
| 9 | NEAL | NEPA | 0.92 | 0.70 | 0.85 |
| 10 | NEAL | NENE | 0.95 | 0.77 | 0.89 |
| 11 | NEAL | NEDI | 0.97 | 0.82 | 0.94 |
| 12 | NEDI | NEAL | 0.97 | 0.85 | 0.94 |
| 13 | NEDI | NERO | 0.98 | 0.88 | 0.94 |
| 14 | NEDI | NEBA | 0.92 | 0.74 | 0.55 |
| 15 | NEDI | NESL | 0.92 | 0.73 | 0.52 |
| 16 | NERO | NEDI | 0.98 | 0.94 | 0.95 |
| 17 | NERO | ANSR | 0.94 | 0.86 | 0.81 |
| 18 | NERO | NETB | 0.98 | 0.94 | 0.92 |
| 19 | NERO | NEEV | 0.98 | 0.93 | 0.90 |
| 20 | NERO | NEBA | 0.96 | 0.90 | 0.80 |
| 21 | NERO | NESL | 0.96 | 0.89 | 0.78 |
| 22 | MUJA | ANAL | 0.94 | 0.85 | 0.88 |
| 23 | MUJA | ANLU | 0.93 | 0.82 | 0.83 |
| 24 | EFACU | ANAL | 0.93 | 0.82 | 0.85 |
| 25 | EFACU | ANLU | 0.94 | 0.83 | 0.85 |
| 26 | ANAL | MUJA | 0.94 | 0.87 | 0.89 |
| 27 | ANAL | ANLU | 0.99 | 0.98 | 0.98 |
| 28 | ANAL | ANSR | 0.93 | 0.84 | 0.79 |
| 29 | ANAL | NETB | 0.92 | 0.82 | 0.80 |
| 30 | ANAL | NEEV | 0.91 | 0.79 | 0.76 |
| 31 | ANLU | NEAL | 0.92 | 0.83 | 0.81 |
| 32 | ANLU | NEDI | 0.94 | 0.88 | 0.86 |
| 33 | ANLU | MUJA | 0.93 | 0.85 | 0.86 |
| 34 | ANLU | EFACU | 0.94 | 0.87 | 0.88 |

Table 5.13 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 35 | ANLU | ANAL | 0.99 | 0.99 | 0.99 |
| 36 | ANLU | ANSR | 0.95 | 0.89 | 0.87 |
| 37 | ANLU | NETB | 0.94 | 0.87 | 0.86 |
| 38 | ANLU | NEEV | 0.93 | 0.85 | 0.83 |
| 39 | ATCH | AYSA | 0.92 | 0.84 | 0.76 |
| 40 | ATCH | ANSR | 0.93 | 0.86 | 0.86 |
| 41 | AYSA | ATCH | 0.92 | 0.79 | 0.83 |
| 42 | AYSA | ANSR | 0.93 | 0.80 | 0.83 |
| 43 | ANSR | NEDI | 0.92 | 0.85 | 0.80 |
| 44 | ANSR | NERO | 0.94 | 0.88 | 0.86 |
| 45 | ANSR | ANAL | 0.93 | 0.86 | 0.85 |
| 46 | ANSR | ANLU | 0.95 | 0.90 | 0.89 |
| 47 | ANSR | ATCH | 0.93 | 0.87 | 0.86 |
| 48 | ANSR | AYSA | 0.93 | 0.87 | 0.75 |
| 49 | ANSR | NETB | 0.98 | 0.96 | 0.97 |
| 50 | ANSR | NEEV | 0.98 | 0.95 | 0.95 |
| 51 | ANSR | NEBA | 0.96 | 0.91 | 0.90 |
| 52 | ANSR | NESL | 0.95 | 0.91 | 0.89 |
| 53 | NETB | NEDI | 0.95 | 0.91 | 0.86 |
| 54 | NETB | NERO | 0.98 | 0.96 | 0.94 |
| 55 | NETB | ANAL | 0.92 | 0.84 | 0.84 |
| 56 | NETB | ANLU | 0.94 | 0.88 | 0.88 |
| 57 | NETB | ANSR | 0.98 | 0.97 | 0.96 |
| 58 | NETB | NEEV | 1.00 | 0.99 | 0.99 |
| 59 | NETB | NEBA | 0.98 | 0.96 | 0.94 |
| 60 | NETB | NESL | 0.98 | 0.95 | 0.93 |
| 61 | NEEV | NEDI | 0.95 | 0.90 | 0.83 |
| 62 | NEEV | NERO | 0.98 | 0.95 | 0.92 |
| 63 | NEEV | ANAL | 0.91 | 0.82 | 0.81 |
| 64 | NEEV | ANLU | 0.93 | 0.86 | 0.86 |
| 65 | NEEV | ANSR | 0.98 | 0.95 | 0.95 |
| 66 | NEEV | NEBA | 0.99 | 0.97 | 0.96 |
| 67 | NEEV | NESL | 0.98 | 0.96 | 0.95 |
| 68 | NEBA | NEDI | 0.92 | 0.84 | 0.76 |

Table 5.13 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 69 | NEBA | NERO | 0.96 | 0.90 | 0.86 |
| 70 | NEBA | ANSR | 0.96 | 0.90 | 0.91 |
| 71 | NEBA | NETB | 0.98 | 0.94 | 0.95 |
| 72 | NEBA | NEEV | 0.99 | 0.95 | 0.97 |
| 73 | NEBA | NESL | 1.00 | 0.98 | 1.00 |
| 74 | NESL | NEDI | 0.92 | 0.83 | 0.74 |
| 75 | NESL | NERO | 0.96 | 0.89 | 0.85 |
| 76 | NESL | ANSR | 0.95 | 0.89 | 0.90 |
| 77 | NESL | NETB | 0.98 | 0.93 | 0.94 |
| 78 | NESL | NEEV | 0.98 | 0.94 | 0.96 |
| 79 | NESL | NEBA | 1.00 | 0.97 | 1.00 |

The performances by the two methods for the GSA WAM are tabulated in Table 5.14. The average NSE values are 0.80 for the existing method, 0.82 for the proposed method, respectively. The proposed method leads to better performances than the existing method at 32 pairs out of total 58 pairs. This indicates that the proposed method slightly enhances the performance of the regional statistical method for the GSA WAM. However, both methods generate two unsatisfied performances (NSE value < 0.5) at four different pairs. There are no differences between the performances by both methods in this point of view.

Table 5.15 lists the NSE values at each pair to show the performances by both methods for the Trinity WAM. The existing method has 0.77 NSE value in average, and the proposed method has 0.82 NSE value in average. The proposed method generates better performances than the existing method at 121 pairs out of total 194 pairs.

Table 5.14 Comparative Evaluation of Performances by Both Methods for the GSA WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 1 | CP02 | CP01 | 0.91 | 0.81 | 0.80 |
| 2 | CP01 | CP02 | 0.91 | 0.82 | 0.82 |
| 3 | CP03 | CP02 | 0.99 | 0.97 | 0.98 |
| 4 | CP04 | CP02 | 0.98 | 0.95 | 0.96 |
| 5 | CP06 | CP02 | 0.94 | 0.52 | 0.55 |
| 6 | CP02 | CP03 | 0.99 | 0.99 | 0.98 |
| 7 | CP04 | CP03 | 0.99 | 0.98 | 0.98 |
| 8 | CP06 | CP03 | 0.96 | 0.57 | 0.71 |
| 9 | CP02 | CP04 | 0.98 | 0.96 | 0.96 |
| 10 | CP03 | CP04 | 0.99 | 0.97 | 0.97 |
| 11 | CP06 | CP04 | 0.98 | 0.62 | 0.71 |
| 12 | CP02 | CP06 | 0.94 | 0.88 | 0.79 |
| 13 | CP03 | CP06 | 0.96 | 0.90 | 0.84 |
| 14 | CP04 | CP06 | 0.98 | 0.94 | 0.86 |
| 15 | CP09 | CP08 | 0.99 | 0.91 | 0.96 |
| 16 | CP10 | CP08 | 0.91 | 0.66 | 0.77 |
| 17 | CP08 | CP09 | 0.99 | 0.83 | 0.96 |
| 18 | CP10 | CP09 | 0.92 | 0.69 | 0.79 |
| 19 | CP08 | CP10 | 0.91 | 0.71 | 0.82 |
| 20 | CP09 | CP10 | 0.92 | 0.80 | 0.81 |
| 21 | CP15 | CP14 | 1.00 | 0.99 | 0.99 |
| 22 | CP38 | CP14 | 0.95 | 0.68 | 0.68 |
| 23 | CPEST | CP14 | 0.94 | 0.71 | 0.71 |
| 24 | CP14 | CP15 | 1.00 | 0.99 | 0.99 |
| 25 | CP38 | CP15 | 0.95 | 0.70 | 0.71 |
| 26 | CPEST | CP15 | 0.94 | 0.73 | 0.74 |
| 27 | CP27 | CP21 | 0.94 | 0.88 | 0.69 |
| 28 | CP28 | CP21 | 0.92 | 0.64 | 0.04 |
| 29 | CP27 | CP23 | 0.94 | 0.88 | 0.79 |
| 30 | CP28 | CP23 | 0.92 | 0.64 | 0.30 |
| 31 | CP261 | CP25 | 0.99 | 0.90 | 0.96 |
| 32 | CP262 | CP25 | 0.99 | 0.94 | 0.97 |
| 33 | CP263 | CP25 | 0.99 | 0.95 | 0.97 |
| 34 | CP25 | CP261 | 0.99 | 0.97 | 0.97 |

Table 5.14 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 35 | CP25 | CP262 | 0.99 | 0.97 | 0.98 |
| 36 | CP21 | CP27 | 0.94 | 0.84 | 0.82 |
| 37 | CP23 | CP27 | 0.94 | 0.87 | 0.86 |
| 38 | CP28 | CP27 | 0.99 | 0.83 | 0.87 |
| 39 | CP29 | CP27 | 0.94 | 0.71 | 0.74 |
| 40 | CP32 | CP27 | 0.92 | 0.48 | 0.54 |
| 41 | CP21 | CP28 | 0.92 | 0.80 | 0.66 |
| 42 | CP23 | CP28 | 0.92 | 0.83 | 0.72 |
| 43 | CP27 | CP28 | 0.99 | 0.98 | 0.92 |
| 44 | CP29 | CP28 | 0.95 | 0.75 | 0.90 |
| 45 | CP32 | CP28 | 0.94 | 0.54 | 0.85 |
| 46 | CP27 | CP29 | 0.94 | 0.87 | 0.84 |
| 47 | CP28 | CP29 | 0.95 | 0.73 | 0.91 |
| 48 | CP32 | CP29 | 0.98 | 0.67 | 0.95 |
| 49 | CP27 | CP32 | 0.92 | 0.83 | 0.78 |
| 50 | CP28 | CP32 | 0.94 | 0.70 | 0.88 |
| 51 | CP29 | CP32 | 0.98 | 0.83 | 0.96 |
| 52 | CP38 | CP37 | 0.93 | 0.64 | 0.83 |
| 53 | CPEST | CP37 | 0.92 | 0.68 | 0.81 |
| 54 | CP14 | CP38 | 0.95 | 0.88 | 0.80 |
| 55 | CP15 | CP38 | 0.95 | 0.90 | 0.82 |
| 56 | CP37 | CP38 | 0.93 | 0.21 | 0.76 |
| 57 | CP14 | CPEST | 0.94 | 0.87 | 0.81 |
| 58 | CP15 | CPEST | 0.94 | 0.88 | 0.82 |

This apparently shows that the proposed method can improve the regional statistical method for the Trinity WAM. The existing method causes 11 unsatisfied (NSE value < 0.5), and 6 unacceptable performances (NSE value < 0), respectively, while the proposed method leads to only 9 unsatisfied performances. This means that the proposed method is expected to generate more stable and accurate performances than the existing method.

Table 5.15 Comparative Evaluation of Performances by Both Methods for the Trinity WAM

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 1 | 8WTJA | 8WTBO | 0.93 | -0.58 | 0.81 |
| 2 | 8BSBR | 8WTBO | 0.93 | 0.40 | 0.86 |
| 3 | 8WTBO | 8WTJA | 0.93 | -0.01 | 0.85 |
| 4 | 8WTBO | 8BSBR | 0.93 | 0.02 | 0.83 |
| 5 | 8WTBO | 8WTFW | 0.97 | 0.13 | 0.89 |
| 6 | 8WTBO | 8WTGP | 0.95 | 0.08 | 0.81 |
| 7 | 8WTBO | 8DNJU | 0.94 | 0.03 | 0.77 |
| 8 | 8WTBO | 8DNGR | 0.92 | -0.02 | 0.57 |
| 9 | 8WTBO | 8TRDA | 0.92 | -0.02 | 0.07 |
| 10 | 8CTAL | 8CTBE | 0.97 | -0.63 | 0.84 |
| 11 | 8CTAL | 8CTFW | 0.97 | -0.65 | 0.68 |
| 12 | 8CTBE | 8CTAL | 0.97 | 0.40 | 0.90 |
| 13 | 8CTBE | 8CTFW | 0.99 | 0.47 | 0.97 |
| 14 | 8CTFW | 8CTAL | 0.97 | 0.63 | 0.85 |
| 15 | 8CTFW | 8CTBE | 0.99 | 0.70 | 0.97 |
| 16 | 8WTFW | 8WTBO | 0.97 | 0.56 | 0.92 |
| 17 | 8WTFW | 8WTGP | 0.99 | 0.63 | 0.97 |
| 18 | 8WTFW | 8DNJU | 0.94 | 0.47 | 0.86 |
| 19 | 8WTFW | 8DNGR | 0.94 | 0.47 | 0.79 |
| 20 | 8WTFW | 8TRDA | 0.96 | 0.54 | 0.59 |
| 21 | 8WTFW | 8TRRS | 0.93 | 0.45 | 0.29 |
| 22 | 8WTFW | 8TRTR | 0.92 | 0.42 | 0.22 |
| 23 | 8WTGP | 8WTBO | 0.95 | 0.62 | 0.87 |
| 24 | 8WTGP | 8WTFW | 0.99 | 0.72 | 0.98 |
| 25 | 8WTGP | 8DNJU | 0.92 | 0.53 | 0.84 |
| 26 | 8WTGP | 8DNGR | 0.93 | 0.55 | 0.81 |
| 27 | 8WTGP | 8TRDA | 0.97 | 0.66 | 0.70 |
| 28 | 8WTGP | 8TRRS | 0.95 | 0.59 | 0.46 |
| 29 | 8WTGP | 8TRTR | 0.94 | 0.58 | 0.41 |
| 30 | 8ELSA | 8IDPP | 0.92 | 0.83 | 0.83 |
| 31 | 8ELSA | 8CLSA | 0.98 | 0.94 | 0.86 |
| 32 | 8ELSA | 8ELLE | 0.92 | 0.83 | 0.82 |
| 33 | 8ELSA | 8DNJU | 0.94 | 0.87 | 0.73 |
| 34 | 8ELSA | 8DNGR | 0.93 | 0.86 | 0.78 |

Table 5.15 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 35 | 8ELSA | 8TRDA | 0.91 | 0.82 | 0.82 |
| 36 | 8IDPP | 8ELSA | 0.92 | 0.83 | 0.81 |
| 37 | 8IDPP | 8CLSA | 0.92 | 0.83 | 0.77 |
| 38 | 8IDPP | 8ELLE | 0.98 | 0.95 | 0.95 |
| 39 | 8IDPP | 8DNGR | 0.93 | 0.85 | 0.77 |
| 40 | 8IDPP | 8TRDA | 0.95 | 0.89 | 0.88 |
| 41 | 8IDPP | 8TRRS | 0.93 | 0.85 | 0.85 |
| 42 | 8CLSA | 8ELSA | 0.98 | 0.88 | 0.69 |
| 43 | 8CLSA | 8IDPP | 0.92 | 0.73 | 0.56 |
| 44 | 8CLSA | 8ELLE | 0.94 | 0.77 | 0.45 |
| 45 | 8CLSA | 8DNJU | 0.97 | 0.85 | 0.92 |
| 46 | 8CLSA | 8DNGR | 0.95 | 0.82 | 0.91 |
| 47 | 8CLSA | 8TRDA | 0.93 | 0.77 | 0.78 |
| 48 | 8ELLE | 8ELSA | 0.92 | 0.82 | 0.84 |
| 49 | 8ELLE | 8IDPP | 0.98 | 0.92 | 0.96 |
| 50 | 8ELLE | 8CLSA | 0.94 | 0.84 | 0.77 |
| 51 | 8ELLE | 8DNJU | 0.94 | 0.84 | 0.68 |
| 52 | 8ELLE | 8DNGR | 0.96 | 0.87 | 0.78 |
| 53 | 8ELLE | 8TRDA | 0.97 | 0.90 | 0.89 |
| 54 | 8ELLE | 8ETMK | 0.91 | 0.82 | 0.80 |
| 55 | 8ELLE | 8TRRS | 0.95 | 0.87 | 0.89 |
| 56 | 8ELLE | 8TRTR | 0.93 | 0.84 | 0.86 |
| 57 | 8DNJU | 8WTBO | 0.94 | 0.59 | 0.84 |
| 58 | 8DNJU | 8WTFW | 0.94 | 0.58 | 0.87 |
| 59 | 8DNJU | 8WTGP | 0.92 | 0.54 | 0.84 |
| 60 | 8DNJU | 8ELSA | 0.94 | 0.60 | 0.23 |
| 61 | 8DNJU | 8CLSA | 0.97 | 0.67 | 0.89 |
| 62 | 8DNJU | 8ELLE | 0.94 | 0.57 | 0.02 |
| 63 | 8DNJU | 8DNGR | 0.98 | 0.70 | 0.93 |
| 64 | 8DNJU | 8TRDA | 0.95 | 0.61 | 0.65 |
| 65 | 8DNGR | 8WTBO | 0.92 | 0.72 | 0.77 |
| 66 | 8DNGR | 8WTFW | 0.94 | 0.75 | 0.85 |
| 67 | 8DNGR | 8WTGP | 0.93 | 0.73 | 0.85 |
| 68 | 8DNGR | 8ELSA | 0.93 | 0.75 | 0.53 |

Table 5.15 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 69 | 8DNGR | 8IDPP | 0.93 | 0.74 | 0.56 |
| 70 | 8DNGR | 8CLSA | 0.95 | 0.80 | 0.90 |
| 71 | 8DNGR | 8ELLE | 0.96 | 0.79 | 0.47 |
| 72 | 8DNGR | 8DNJU | 0.98 | 0.86 | 0.94 |
| 73 | 8DNGR | 8TRDA | 0.97 | 0.82 | 0.84 |
| 74 | 8DNGR | 8TRRS | 0.93 | 0.74 | 0.66 |
| 75 | 8DNGR | 8TRTR | 0.92 | 0.70 | 0.60 |
| 76 | 8TRDA | 8WTBO | 0.92 | 0.84 | 0.68 |
| 77 | 8TRDA | 8WTFW | 0.96 | 0.91 | 0.81 |
| 78 | 8TRDA | 8WTGP | 0.97 | 0.93 | 0.85 |
| 79 | 8TRDA | 8ELSA | 0.91 | 0.82 | 0.74 |
| 80 | 8TRDA | 8IDPP | 0.95 | 0.89 | 0.84 |
| 81 | 8TRDA | 8CLSA | 0.93 | 0.86 | 0.85 |
| 82 | 8TRDA | 8ELLE | 0.97 | 0.93 | 0.83 |
| 83 | 8TRDA | 8DNJU | 0.95 | 0.89 | 0.82 |
| 84 | 8TRDA | 8DNGR | 0.97 | 0.92 | 0.90 |
| 85 | 8TRDA | 8ETMK | 0.91 | 0.82 | 0.59 |
| 86 | 8TRDA | 8TRRS | 0.98 | 0.96 | 0.95 |
| 87 | 8TRDA | 8TRTR | 0.97 | 0.93 | 0.91 |
| 88 | 8ETMK | 8ELLE | 0.91 | 0.78 | 0.81 |
| 89 | 8ETMK | 8TRDA | 0.91 | 0.77 | 0.75 |
| 90 | 8ETMK | 8SGPR | 0.98 | 0.88 | 0.96 |
| 91 | 8ETMK | 8ETLA | 0.97 | 0.86 | 0.93 |
| 92 | 8ETMK | 8ETFO | 0.96 | 0.85 | 0.88 |
| 93 | 8ETMK | 8ETCR | 0.96 | 0.84 | 0.88 |
| 94 | 8ETMK | 8TRRS | 0.94 | 0.81 | 0.84 |
| 95 | 8ETMK | 8TRTR | 0.94 | 0.81 | 0.84 |
| 96 | 8SGPR | 8ETMK | 0.98 | 0.90 | 0.95 |
| 97 | 8SGPR | 8ETLA | 0.96 | 0.87 | 0.89 |
| 98 | 8SGPR | 8ETFO | 0.96 | 0.87 | 0.83 |
| 99 | 8SGPR | 8ETCR | 0.96 | 0.87 | 0.84 |
| 100 | 8SGPR | 8TRRS | 0.93 | 0.82 | 0.83 |
| 101 | 8SGPR | 8TRTR | 0.93 | 0.81 | 0.83 |
| 102 | 8ETLA | 8ETMK | 0.97 | 0.84 | 0.94 |

Table 5.15 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 103 | 8ETLA | 8SGPR | 0.96 | 0.83 | 0.92 |
| 104 | 8ETLA | 8ETFO | 0.98 | 0.86 | 0.95 |
| 105 | 8ETLA | 8ETCR | 0.98 | 0.85 | 0.95 |
| 106 | 8ETLA | 8TRRS | 0.92 | 0.77 | 0.80 |
| 107 | 8ETLA | 8TRTR | 0.92 | 0.77 | 0.80 |
| 108 | 8ETFO | 8ETMK | 0.96 | 0.78 | 0.91 |
| 109 | 8ETFO | 8SGPR | 0.96 | 0.78 | 0.89 |
| 110 | 8ETFO | 8ETLA | 0.98 | 0.81 | 0.96 |
| 111 | 8ETFO | 8ETCR | 1.00 | 0.83 | 0.99 |
| 112 | 8ETFO | 8TRRS | 0.93 | 0.74 | 0.77 |
| 113 | 8ETFO | 8TRTR | 0.93 | 0.74 | 0.78 |
| 114 | 8ETCR | 8ETMK | 0.96 | 0.79 | 0.91 |
| 115 | 8ETCR | 8SGPR | 0.96 | 0.79 | 0.89 |
| 116 | 8ETCR | 8ETLA | 0.98 | 0.82 | 0.95 |
| 117 | 8ETCR | 8ETFO | 1.00 | 0.84 | 0.99 |
| 118 | 8ETCR | 8TRRS | 0.93 | 0.75 | 0.78 |
| 119 | 8ETCR | 8TRTR | 0.93 | 0.75 | 0.79 |
| 120 | 8TRRS | 8WTFW | 0.93 | 0.86 | 0.71 |
| 121 | 8TRRS | 8WTGP | 0.95 | 0.89 | 0.76 |
| 122 | 8TRRS | 8IDPP | 0.93 | 0.85 | 0.83 |
| 123 | 8TRRS | 8ELLE | 0.95 | 0.90 | 0.84 |
| 124 | 8TRRS | 8DNGR | 0.93 | 0.86 | 0.80 |
| 125 | 8TRRS | 8TRDA | 0.98 | 0.96 | 0.95 |
| 126 | 8TRRS | 8ETMK | 0.94 | 0.88 | 0.77 |
| 127 | 8TRRS | 8SGPR | 0.93 | 0.86 | 0.79 |
| 128 | 8TRRS | 8ETLA | 0.92 | 0.85 | 0.67 |
| 129 | 8TRRS | 8ETFO | 0.93 | 0.86 | 0.57 |
| 130 | 8TRRS | 8ETCR | 0.93 | 0.86 | 0.60 |
| 131 | 8TRRS | 8TRTR | 0.99 | 0.98 | 0.98 |
| 132 | 8TRRS | 8TROA | 0.93 | 0.86 | 0.85 |
| 133 | 8TRTR | 8WTFW | 0.92 | 0.84 | 0.68 |
| 134 | 8TRTR | 8WTGP | 0.94 | 0.88 | 0.74 |
| 135 | 8TRTR | 8ELLE | 0.93 | 0.86 | 0.81 |
| 136 | 8TRTR | 8DNGR | 0.92 | 0.84 | 0.77 |

Table 5.15 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 137 | 8TRTR | 8TRDA | 0.97 | 0.93 | 0.93 |
| 138 | 8TRTR | 8ETMK | 0.94 | 0.87 | 0.77 |
| 139 | 8TRTR | 8SGPR | 0.93 | 0.86 | 0.80 |
| 140 | 8TRTR | 8ETLA | 0.92 | 0.84 | 0.68 |
| 141 | 8TRTR | 8ETFO | 0.93 | 0.86 | 0.59 |
| 142 | 8TRTR | 8ETCR | 0.93 | 0.86 | 0.62 |
| 143 | 8TRTR | 8TRRS | 0.99 | 0.98 | 0.98 |
| 144 | 8TRTR | 8TROA | 0.94 | 0.89 | 0.89 |
| 145 | 8CEKE | 8KGKA | 0.95 | 0.84 | 0.85 |
| 146 | 8CEKE | 8CEMA | 0.98 | 0.89 | 0.96 |
| 147 | 8KGKA | 8CEKE | 0.95 | 0.77 | 0.89 |
| 148 | 8KGKA | 8CEMA | 0.99 | 0.82 | 0.94 |
| 149 | 8CEMA | 8CEKE | 0.98 | 0.90 | 0.96 |
| 150 | 8CEMA | 8KGKA | 0.99 | 0.91 | 0.92 |
| 151 | 8RIDA | 8RIRI | 0.98 | 0.95 | 0.95 |
| 152 | 8RIDA | 8RIFA | 0.95 | 0.89 | 0.88 |
| 153 | 8RIRI | 8RIDA | 0.98 | 0.93 | 0.96 |
| 154 | 8RIRI | 8RIFA | 0.97 | 0.90 | 0.92 |
| 155 | 8WABA | 8CHCO | 0.98 | 0.95 | 0.95 |
| 156 | 8WABA | 8RIFA | 0.94 | 0.86 | 0.80 |
| 157 | 8CHCO | 8WABA | 0.98 | 0.96 | 0.96 |
| 158 | 8CHCO | 8RIFA | 0.96 | 0.92 | 0.89 |
| 159 | 8RIFA | 8RIDA | 0.95 | 0.88 | 0.90 |
| 160 | 8RIFA | 8RIRI | 0.97 | 0.90 | 0.92 |
| 161 | 8RIFA | 8WABA | 0.94 | 0.86 | 0.87 |
| 162 | 8RIFA | 8CHCO | 0.96 | 0.90 | 0.92 |
| 163 | 8TROA | 8TRRS | 0.93 | 0.85 | 0.85 |
| 164 | 8TROA | 8TRTR | 0.94 | 0.88 | 0.88 |
| 165 | 8TROA | 8TRCR | 0.99 | 0.96 | 0.97 |
| 166 | 8TROA | 8TRMI | 0.99 | 0.96 | 0.97 |
| 167 | 8TROA | 8TRRI | 0.97 | 0.93 | 0.94 |
| 168 | 8TROA | 8TRRO | 0.94 | 0.88 | 0.88 |
| 169 | 8TROA | 8TRGB | 0.93 | 0.86 | 0.85 |
| 170 | 8TRCR | 8TROA | 0.99 | 0.95 | 0.97 |

Table 5.15 (Continued)

| No. | Assumed Ungauged Site (Y) | Assumed Gauged Site (X) | Correlation Coefficient (r) | Nash-Sutcliffe Coefficient (Naturalized vs. Transferred) Existing Method | Proposed Method |
|---|---|---|---|---|---|
| 171 | 8TRCR | 8TRMI | 1.00 | 0.98 | 0.99 |
| 172 | 8TRCR | 8TRRI | 0.99 | 0.97 | 0.98 |
| 173 | 8TRCR | 8TRRO | 0.97 | 0.92 | 0.94 |
| 174 | 8TRCR | 8TRGB | 0.96 | 0.90 | 0.91 |
| 175 | 8TRMI | 8TROA | 0.99 | 0.95 | 0.97 |
| 176 | 8TRMI | 8TRCR | 1.00 | 0.97 | 0.99 |
| 177 | 8TRMI | 8TRRI | 0.99 | 0.97 | 0.98 |
| 178 | 8TRMI | 8TRRO | 0.97 | 0.93 | 0.94 |
| 179 | 8TRMI | 8TRGB | 0.96 | 0.90 | 0.91 |
| 180 | 8TRRI | 8TROA | 0.97 | 0.92 | 0.94 |
| 181 | 8TRRI | 8TRCR | 0.99 | 0.96 | 0.98 |
| 182 | 8TRRI | 8TRMI | 0.99 | 0.96 | 0.98 |
| 183 | 8TRRI | 8TRRO | 0.99 | 0.95 | 0.97 |
| 184 | 8TRRI | 8TRGB | 0.98 | 0.93 | 0.95 |
| 185 | 8TRRO | 8TROA | 0.94 | 0.86 | 0.87 |
| 186 | 8TRRO | 8TRCR | 0.97 | 0.91 | 0.93 |
| 187 | 8TRRO | 8TRMI | 0.97 | 0.92 | 0.94 |
| 188 | 8TRRO | 8TRRI | 0.99 | 0.94 | 0.97 |
| 189 | 8TRRO | 8TRGB | 1.00 | 0.96 | 0.99 |
| 190 | 8TRGB | 8TROA | 0.93 | 0.82 | 0.85 |
| 191 | 8TRGB | 8TRCR | 0.96 | 0.88 | 0.91 |
| 192 | 8TRGB | 8TRMI | 0.96 | 0.88 | 0.91 |
| 193 | 8TRGB | 8TRRI | 0.98 | 0.91 | 0.95 |
| 194 | 8TRGB | 8TRRO | 1.00 | 0.95 | 0.99 |

As a result of the comparative evaluation of both methods, the performances by both methods are very similar if statistical parameters have relatively strong linear relationship with regional variables like the Sabine and Neches WAM. However, if not, the proposed method should enhance the performance of the regional statistical method like the GSA and Trinity WAM.

# CHAPTER VI
# DISAGGREGATION OF MONTHLY TO DAILY NATURALIZED FLOWS USING THE SWAT MODEL

The Soil and Water Assessment Tool (SWAT) is introduced in Chapter I and applied in Chapter IV to synthesize monthly naturalized flows for periods of missing data. Methods for compiling SWAT input data and calibrating parameters are described in Chapter IV. SWAT is applied in the present Chapter VI for the purpose of disaggregating monthly naturalized flows to daily.

## 6.1 Watershed Delineation

The SWAT rainfall-runoff model is applied to develop sequences of daily streamflow, representing natural conditions without water resource development and use, for periods-of-analysis at control points of interest in the three river basins. These sequences of daily streamflow provide daily flow patterns for disaggregating the monthly WAM naturalized flows to daily. The SIMD simulation model converts monthly naturalized flows to daily based on these daily flow patterns hydrographs while preserving the monthly volumes.

The SWAT models for the Sabine, Neches, and GSA River Basins are developed, including all control points of interest that are distributed from headwater to downstream. In general, the SWAT automatically delineates multiple subwatersheds for a river basin, but the locations of pertinent control points are manually assigned in the delineated models with their exact coordinates from the GIS data in WAM datasets.

Measured daily rainfall data, described in Chapter IV, are adopted for the SWAT models of the three river basins, and other climate data are also generated within the SWAT model by its weather generator. The three SWAT models initially develop monthly and daily flow sequences for certain periods for the model calibrations. Each SWAT model has warm-up simulation periods, 1938-1939 (2 years) for the Sabine and Neches River Basins and 1930-1933 (4 years) for GSA River Basins, respectively.

### 6.1.1 Sabine River Basin

The SWAT model for the Sabine River Basin is developed, including eighteen primary control points and three secondary control points that are tabulated in Table 6.1. Two secondary control points (E4642A and E4658A) are included for the sites of dams, and another is the site of Senate Bill 3 (SB3) environmental flow standards. Environmental flow standards have been established through the SB3 process at five USGS gaging stations (Wurbs *et al.*, 2014a), listed in Table 6.2. The delineated basin has 98 subwatersheds and covers the 21 interested control points, as shown in Figure 6.1. The model has daily rainfall data covering from 1938 to 2013. The period-of-analysis of the version of the daily Sabine WAM used in this research extends from January 1, 1940 through December 31, 2013 (Wurbs *et al.*, 2014a).

Table 6.1 Secondary Control Points

| Control Point | Location | Gage Number | Area (mile$^2$) | Period-of-Record |
|---|---|---|---|---|
| | Large Reservoirs | | | |
| E4642A | Cherokee Bayou at Cherokee Dam | | 158.5 | |
| E4658A | Sabine River at Toledo Bend Dam | | 7,199 | |
| | SB-3 Environmental Flow Standards | | | |
| 29500 | Big Cow Creek near Newton, TX | 8029500 | 128 | 5/52 to present |

Table 6.2 Sabine WAM Control Point Locations for SB3 Environmental Flow Standards

| Control Points | USGS Gage | Location | Watershed Area (sq. miles) | Period-of-Record |
|---|---|---|---|---|
| BSBS | 08019500 | Big Sandy Creek near Big Sandy | 231 | 1939-present |
| SRGW | 08020000 | Sabine River near Gladewater | 2,791 | 1932-present |
| SRBE | 08022040 | Sabine River near Beckville | 3,589 | 1938-present |
| 29500 | 08029500 | Big Cow Creek near Newton | 128 | 1952-present |
| SRRL | 08030500 | Sabine River near Ruliff | 9,329 | 1924-present |

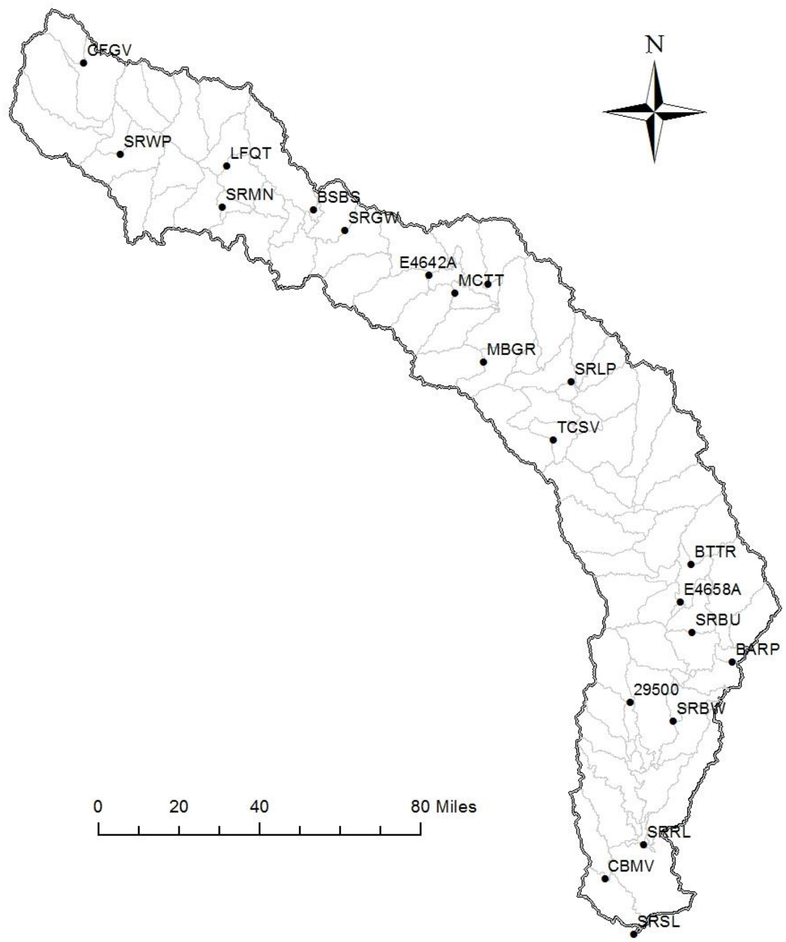



Figure 6.1 Model Delineation for the Sabine River Basin

6.1.2 Neches River Basin

The SWAT model for the Neches River Basin includes twenty primary control points. Environmental flow standards have been established through the SB3 process at five USGS gaging stations (Wurbs *et al.*, 2014b), listed in Table 6.3. The delineated basin has 123 sub-watersheds and covers the 20 pertinent control points, shown in Figure 6.2.

The model has daily rainfall data for 1938 to 2013 which covers the complete period-of-analysis of the Neches WAM that recently extended to cover from January 1, 1940 through December 31, 2013 (Wurbs *et al.*, 2014b).

Table 6.3 Neches WAM Control Point Locations for SB3 Environmental Flow Standards

| Control Point | USGS Gage No. | Location | Watershed Area (square miles) | Period-of-Record |
|---|---|---|---|---|
| NENE | 08032000 | Neches River at Neches | 1,145 | 1939-present |
| NERO | 08033500 | Neches River near Rockland | 3,636 | 1903-present |
| ANAL | 08036500 | Angelina River near Alto | 1,276 | 1940-present |
| NEEV | 08041000 | Neches River at Evadale | 7,951 | 1904-present |
| VIKO | 08041500 | Village Creek near Kountze | 860 | 1924-present |


Figure 6.2 Model Delineation for the Neches River Basin

### 6.1.3 GSA River Basins

The SWAT model for the GSA River Basins was developed with 38 of the total of 46 primary control points and two secondary control points as listed in Table 6.4. Eight primary control points are excluded for two different reasons: CP75 (San Marcos Springs) is a spring water source, and seven others have relatively small watershed areas. Two secondary control points (C384611 and P382411) incorporating Senate Bill 3 (SB3) environmental flow standards are included. Environmental flow standards have been established through the SB3 process at fifteen USGS gaging stations in the GSA River Basins (Wurbs *et al.*, 2014c) as listed in Table 6.5. The delineated basin has 132 sub-watersheds and covers the 40 selected control points, as shown in Figure 6.3. The model has daily rainfall data cover from 1930 to 2013 for the period-of-analysis of the GSA WAM that recently extended from January 1, 1934 through December 31, 2013 (Wurbs *et al.*, 2014c).

Table 6.4 Thirty Eight Primary and Two Selected Secondary Control Points in the GSA WAM

| CP | USGS Gage | Location | Drainage Area | Period-of-Record |
|---|---|---|---|---|
| | | *Guadalupe River Basin* | (sq. mile) | |
| CP01 | 08167000 | Guadalupe River at Comfort | 838 | 31 May 1939 − present |
| CP02 | 08167500 | Guadalupe River near Spring Branch | 1,315 | 1 Jan 1934 − present |
| CP03 | 08167800 | Guadalupe River at Canyon Lake | 1,432 | 1 Mar 1960 − present |
| CP04 | 08168500 | Guadalupe River at New Braunfels | 1,519 | 19 Dec 1927 − present |
| CP05 | 08169000 | Comal River at New Braunfels | 130 | 19 Dec 1927 − present |
| CP06 | − | Guadalupe River at Lake Wood | 2,103 | − |
| CP08 | 08171000 | Blanco River at Wimberley | 355 | 1 Jan 1934 – present |
| CP09 | 08171300 | Blanco River near Kyle | 412 | 29 May 1956 − present |
| CP10 | 08172000 | San Marcos River at Luling | 839 | 18 Apr 1939 − present |
| CP11 | 08173000 | Plum Creek near Luling | 311 | 1 Jan 1934 – present |
| C384611 | 08173900 | Guadalupe River near Gonzales | 3,490 | 1 Oct 1996 − present |
| CP12 | 08174600 | Peach Creek below Dilworth | 460 | 1 Aug 1959 – present |
| CP13 | 08175000 | Sandies Creek near Westhoff | 549 | 1 Jan 1934 – present |
| CP14 | 08175800 | Guadalupe River at Cuero | 4,935 | 1 Jan 1964 – present |
| CP15 | 08176500 | Guadalupe River at Victoria | 5,196 | 4 Nov 1934 – present |
| CP16 | 08177400 | Coleto Creek Reservoir near Victoria | 493 | storage 1986-2002 |
| CP38 | 08188800 | Guadalupe River near Tivoli | 10,122 | 4 Aug 2000 – present |
| CPEST | − | Guadalupe Estuary | 10,122 | − |

Table 6.4 (Continued)

| CP | USGS Gage | Location | Drainage Area (sq. mile) | Period-of-Record |
|---|---|---|---|---|
| | | *San Antonio River Basin* | | |
| CP17 | – | Olmos Creek at Edwards | 8 | – |
| CP18 | 08178000 | San Antonio River at San Antonio | 44 | 1 Mar 1939 – present |
| CP19 | 08178700 | Salado Creek at San Ant Upper Station | 136 | 7 May 1997 – 5 Dec 2006 |
| CP20 | 08178800 | Salado Creek at San Ant Lower Station | 187 | 1 Sep 1960 – present |
| P382411 | 08178880 | Medina River at Bandera | 328 | 1 Oct 1982 – present |
| CP21 | 08179500 | Medina Lake | 634 | storage 1997-present |
| CP23 | 08180500 | Medina River near Rio Medina | 649 | Oct 1923 – 10 Oct 2007 |
| CP25 | – | San Geronimo Creek at Edwards | 58 | – |
| CP261 | – | Leon Creek at Edwards | 60 | – |
| CP262 | – | Helotes Creek at Edwards | 28 | – |
| CP263 | – | Government Creek at Edwards | 12 | – |
| CP27 | 08180800 | Medina River near Somerset | 962 | Oct 1970 – 9 Sep 2004 |
| CP28 | 08181500 | Medina River at San Antonio | 1,310 | 27 Jul 1939 – present |
| CP29 | 08181800 | San Antonio River near Elmendorf | 1,737 | 1 Oct 1962 – present |
| CP30 | – | Braunig Lake | 9 | – |
| CP31 | 08182500 | Calaveras Creek near Elmendorf | 65 | 1 Oct 54 – 30 Sep 1971 |
| CP32 | 08183500 | San Antonio River near Falls City | 2,108 | 1 May 1925 – present |
| CP33 | 08183900 | Cibolo Creek near Boerne | 68 | 1 Mar 1962 – present |
| CP34 | 08185000 | Cibolo Creek at Selma | 274 | 1 Apr 1946 – present |
| CP35 | 08186000 | Cibolo Creek near Falls City | 825 | 1 Oct 1930 – present |
| CP36 | 08186500 | Ecleto Creek near Runge | 239 | 1 Apr 1962 – present |
| CP37 | 08188500 | San Antonio River at Goliad | 3,906 | 1 Mar 1939 – present |

Table 6.5 GSA WAM Control Point Locations for SB3 Environmental Flow Standards

| No. | CP | Basin | USGS | Location | Drainage Area (sq. miles) |
|---|---|---|---|---|---|
| 1 | CP01 | G | 08167000 | Guadalupe River at Comfort | 838 |
| 2 | CP02 | G | 08167500 | Guadalupe River near Spring Branch | 1,315 |
| 3 | CP08 | G | 08171000 | Blanco River at Wimberley | 355 |
| 4 | CP10 | G | 08172000 | San Marcos River at Luling | 839 |
| 5 | CP11 | G | 08173000 | Plum Creek near Luling | 311 |
| 6 | C384611 | G | 08173900 | Guadalupe River at Gonzales | 3,469 |
| 7 | CP13 | G | 08175000 | Sandies Creek near Westhoff | 549 |
| 8 | CP14 | G | 08175800 | Guadalupe River at Cuero | 4,935 |
| 9 | CP15 | G | 08176500 | Guadalupe River at Victoria | 5,196 |
| 10 | P382411 | SA | 08178880 | Medina River at Bandera | 328 |
| 11 | CP28 | SA | 08181500 | Medina River at San Antonio | 1,310 |
| 12 | CP29 | SA | 08181800 | San Antonio River near Elmendorf | 1,737 |
| 13 | CP32 | SA | 08183500 | San Antonio River near Falls City | 2,108 |
| 14 | CP35 | SA | 08186000 | Cibolo Creek near Falls City | 825 |
| 15 | CP37 | SA | 08188500 | San Antonio River at Goliad | 3,906 |

Note) G: Guadalupe River Basin, and SA: San Antonio River Basin

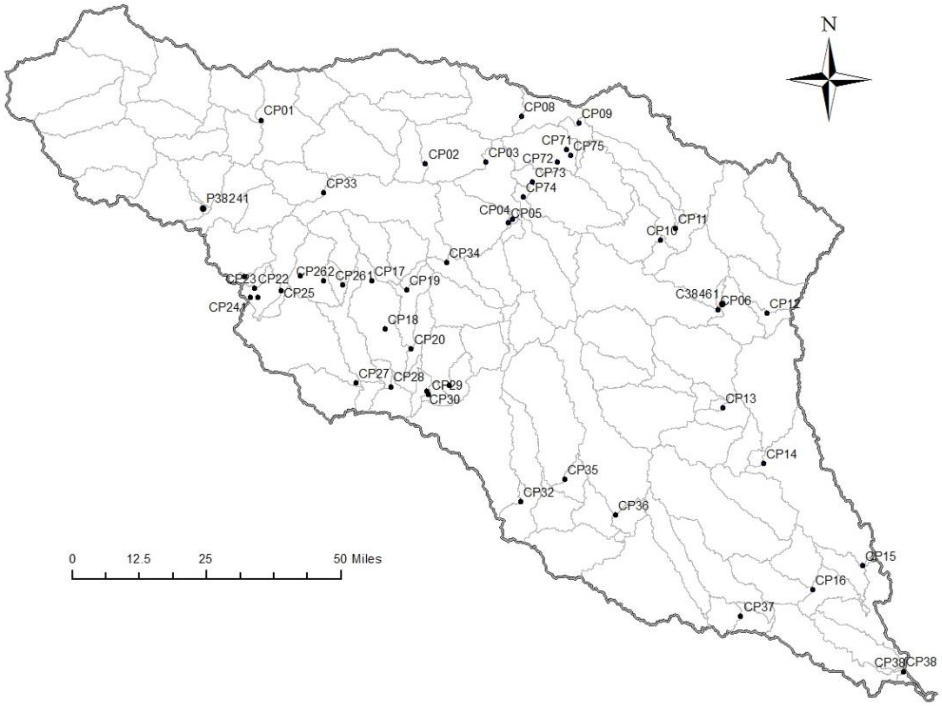



Figure 6.3 Model Delineation for the GSA River Basins

## 6.2 Model Calibration

This research investigates two different calibration strategies: calibrations with monthly and daily flow sequences. The calibrations are performed at multi-sites by the SWAT-CUP model to obtain the calibrated parameters with spatial consistency such as routing effects between up and downstream sites within a river basin. Coefficient of determination ($R^2$) is commonly selected as the objective function. This efficiency criterion has a major advantage that ensures the objective function is not governed by a single or a few badly simulated sites in multisite calibration (Arnold *et al.*, 2012b).

In both the model calibrations, the selected parameters are applied to all watersheds in the Sabine and Neches River Basins. However, the GSA River Basins consist of two major river basins, Guadalupe and San Antonio Rivers. These have also varying land cover and a major aquifer (Edward aquifer). Thus, the selected parameters are applied to 5 representative regions, divided by major land covers and Edward aquifer area in the GSA River Basins. The five regions consist of forest, grass and pasture areas in both river basins, and urban areas in the San Antonio River Basin.

### 6.2.1 Calibration with Monthly Naturalized Flows

The representative control points are selected for multisite calibration. The sites for calibration are selected considering spatial distribution of control points from headwater to downstream within a river basin. The five control points for the Sabine WAM, the six control points for the Neches WAM, and thirteen control points for the GSA WAM are selected for multisite calibrations, respectively. Table 6.6 lists the control points, selected for multisite calibration for the three river basins, and their locations are referred to as shown in Figures 6.1, 6.2, and 6.3, respectively.

The calibration periods for the three river basins are the same as their original periods-of-analysis as listed in Table 6.6. The validations are not necessary because these calibrations are for developing the calibrated models to synthesize daily flow sequences at all relevant points for their periods-of-analysis.

Table 6.6 summarizes the calibration results for the three river basins. The calibrated models for synthesizing daily flow sequences at all relevant sites in the three river basins are eventually prepared through the modification of the parameters, obtained from the model calibrations on the original models.

### 6.2.2 Calibration with Daily USGS Recorded Flows

For developing a calibrated daily SWAT model, it is pivotal to obtain daily recorded flow data, considered under naturalized conditions without any human influences, at a relevant site. In reality, human activities such as diversion of water from a river, dam projects, and navigation structures generally impact river flow regimes, and these tend to increase over time. It is practically impossible to obtain daily pure naturalized flow records for a certain period from USGS gauges, even though the gauge has daily flow records for a long period.

Table 6.6 Monthly Calibration Results of SWAT Models

| Control Points | Coefficient of Determination ($R^2$) (Naturalized vs. SWAT Flows) Without Calibration | With Calibration |
|---|---|---|
| Sabine River Basin (Calibration Period: 1940 to 1998, 59 years) | | |
| LFQT | 0.45 | 0.47 |
| SRMN | 0.69 | 0.77 |
| SRLP | 0.62 | 0.72 |
| SRBU | 0.65 | 0.72 |
| SRSL | 0.69 | 0.72 |
| Neches River Basin (Calibration Period: 1940 to 1996, 57 years) | | |
| NENE | 0.60 | 0.68 |
| ANAL | 0.63 | 0.74 |
| ANSR | 0.65 | 0.73 |
| NERO | 0.70 | 0.81 |
| NEEV | 0.74 | 0.82 |
| NESL | 0.74 | 0.84 |
| GSA River Basins (Calibration Period: 1934 to 1989, 56 years) | | |
| CP02 | 0.63 | 0.74 |
| CP04 | 0.63 | 0.72 |
| CP06 | 0.64 | 0.72 |
| CP10 | 0.70 | 0.72 |
| CP13 | 0.51 | 0.55 |
| CP14 | 0.68 | 0.79 |
| CP15 | 0.68 | 0.80 |
| CP23 | 0.26 | 0.28 |
| CP32 | 0.46 | 0.51 |
| CP34 | 0.42 | 0.53 |
| CP35 | 0.59 | 0.63 |
| CP36 | 0.44 | 0.44 |
| CP37 | 0.60 | 0.74 |

Many researchers have found that dam projects are the human influence with greatest impact on changing flow regimes of rivers. Therefore, the USGS recorded flow data prior to construction of dam projects can be considered to approximate daily naturalized flow sequences, if all other human influences are disregarded.

The Sabine River Basin has 13 major reservoirs. Toledo Bend, Lake Tawakoni, and Lake Fork are considered the reservoirs that most significantly influence the river flows. Toledo Bend was initially impounded in October, 1966, Lake Tawakoni was initially impounded in October, 1960, and Lake Fork was initially impounded in July, 1979. Thus, it can be considered that the recorded flows prior to 1960 were nearly under naturalized conditions. The six control points have the daily recorded flows from 1940 to 1960 without missing data. The four control points of the six control points in total are selected for multisite calibration considering their spatial distribution as listed in Table 6.7.

There are 11 major reservoirs in the Neches River Basin. Sam Rayburn and Palestine reservoirs considerably impact the river flow regimes. The initial impoundation years of Sam Rayburn and Palestine were 1965 and 1962, respectively. Therefore, the recorded flows prior to 1960 are considered practically daily naturalized flows. The seven control points have the daily recorded flows from 1940 to 1960 without missing data. The three control points of the seven control points in total are selected for multisite calibration considering their spatial distribution as listed in Table 6.7.

The GSA River Basins have 9 major reservoirs. Canyon Lake in the Guadalupe River Basin and Medina Lake in the San Antonio River Basin are considered the reservoirs that should remarkably change the river flow regimes. Canyon Lake was initially impounded in 1964, and located upstream of the Guadalupe River. Medina Lake, located upstream of the San Antonio River, has been operated since 1913. Thus, recorded flows prior to 1960 in the Guadalupe River can be considered daily naturalized flows, but Medina Lake has changed flow regimes along the San Antonio River since 1913. There are 9 control points that have the daily recorded flows prior to 1960 in the Guadalupe River Basin. The two control points of the nine control points in total are selected for multisite calibration, considering their spatial distribution and spring water impacts as listed in Table 6.7. The San Antonia River Basin does not have the control points that have the daily recorded flows prior to 1913. However, there are 7 control points that have the daily recorded flows prior to 1960 like the Guadalupe River Basin. Of the 7 control points, three control points are practically selected for multisite calibration as listed in Table 6.7.

Medina Lake cannot impact the flow regimes at Control point CP35, because it is located at a tributary. Even though Medina Lake should influence on the flow regimes at Control point CP32 and CP37, but these influences should be minimized at the two control points.

The SWAT model should have spatially and temporally well-distributed rainfall data covering a basin area and drought and flood years for calibration and validation periods. Calibration and validation periods are determined as listed in Table 6.7 according to two main reasons: (1) the SWAT models have recorded daily rainfall data covering the periods-of-analysis, but there are a number of rainfall gauges with missing data prior to 1950. Therefore, the calibration and validation periods should be determined after 1950, and (2) the calibration period for 1950-1955 (5 years) includes both a serious drought and regular flood years, and the validation period includes both a regular drought and flood years.

Table 6.7 summarizes the calibration and validation results for the three river basins. The Sabine and Neches River Basins show relatively better results, and the GSA River Basins show worse results than the two river basins. Although the values of $R^2$ for the validation periods would decrease than the calibration periods at some control points, all the values of $R^2$ for both the periods are acceptable as listed in Table 6.7. Therefore, the three calibrated daily models are eventually developed to generate daily flow sequences at all relevant sites, if the parameters on the original models are replaced with the calibrated parameters.

## 6.3 Disaggregation of Monthly to Daily Naturalized Flows

SWAT models calibrated by the two calibration strategies generate two different daily flow sequences for the periods-of-analysis for the Sabine, Neches, and GSA River Basin, respectively. In other words, each WAM eventually has the two different daily flow patterns covering the period-of-analysis, generated by calibrated SWAT models based on the monthly naturalized flows and daily USGS recorded flows.

Table 6.7 Daily Calibration Results of SWAT Models

| Control Points | Coefficient of Determination ($R^2$) (Naturalized vs. SWAT flows) Without Calibration (1950-1955) | With Calibration (1950-1955) | Validation (1956-1960) |
|---|---|---|---|
| <u>Sabine River Basin</u> | | | |
| LFQT | 0.10 | 0.37 | 0.60 |
| SRBW | 0.10 | 0.78 | 0.62 |
| SRMN | 0.06 | 0.64 | 0.73 |
| SRBE | 0.10 | 0.64 | 0.77 |
| <u>Neches River</u> | | | |
| ANLU | 0.11 | 0.84 | 0.77 |
| NERO | 0.17 | 0.87 | 0.76 |
| NEEV | 0.10 | 0.90 | 0.76 |
| <u>GSA River</u> | | | |
| CP04 | 0.60 | 0.87 | 0.36 |
| CP15 | 0.02 | 0.59 | 0.67 |
| CP32 | 0.07 | 0.34 | 0.39 |
| CP35 | 0.38 | 0.79 | 0.36 |
| CP37 | 0.06 | 0.74 | 0.47 |

For disaggregation of monthly to daily naturalized flows, monthly naturalized flows data at the relevant control points are firstly extracted from each output of monthly WRAP (SIM) model using the OI record in the HIN file as described in the WRAP Hydrology Manual (Wurbs 2013b). Table 6.8 reproduces the HIN file for the Sabine WAM as an example.

Table 6.8 OI Records in the HIN file

```
** Monthly naturalized flow records from Sabine3M OUT file.
JC  1940  73   1   7
OI     1   2  IN   1   29500   29500
OI     1   2  IN   1    CFGV    CFGV
OI     1   2  IN   1    SRWP    SRWP
OI     1   2  IN   1    SRMN    SRMN
OI     1   2  IN   1    LFQT    LFQT
OI     1   2  IN   1    BSBS    BSBS
OI     1   2  IN   1  E4642A  E4642A
OI     1   2  IN   1  E4658A  E4658A
OI     1   2  IN   1    SRBE    SRBE
OI     1   2  IN   1    MCTT    MCTT
OI     1   2  IN   1    MBGR    MBGR
OI     1   2  IN   1    SRLP    SRLP
OI     1   2  IN   1    BTTR    BTTR
OI     1   2  IN   1    SRBU    SRBU
OI     1   2  IN   1    BARP    BARP
OI     1   2  IN   1    SRBW    SRBW
OI     1   2  IN   1    SRRL    SRRL
OI     1   2  IN   1    CBMV    CBMV
OI     1   2  IN   1    SRSL    SRSL
OI     1   2  IN   1    SRGW    SRGW
OI     1   2  IN   1    TCSV    TCSV
ED
```

The OI records in the HIN file extract monthly naturalized flow sequences for 1940-2013 at 21 control points stored in the FLO file with IN record for the Sabine WAM, 1940-2013 sequences of naturalized flows at 20 primary control points stored in the FLO file with IN records for the Neches WAM, and monthly naturalized flow sequences for the period from 1934 to 2013 at 40 control points stored in the FLO file with IN record for the GSA WAM.

JOBDIS and DFLWS records in the DIN file disaggregate monthly flow sequence stored in the FLO file to daily flow sequence based on daily flow sequence stored in the DCF file as described in the WRAP Daily Manual (Wurbs and Hoffpauir, 2013b). Table 6.9 reproduces a DIN, FLO, and DCF files, respectively, as examples.

Table 6.9 Examples of DIN, FLO, and DCF files

```
JOBDIS        0      4                                                    2   29500
DFLOWS     1940      1    2013      12    1940      1    2013      12      2   29500   29500
END
```

a) An Example of DIN file

```
1940   1   1     17.83
1940   1   2     13.70
1940   1   3     10.88
1940   1   4      9.46
1940   1   5      8.16
```

b) An Example of DCF file

```
IN 29500    1940 27907.0 16239.1  7996.5     0.0 15978.2  2513.1  9179.7 52615.0  4962.7  3426.9 14294.8 73577.1
IN 29500    1941 41934.0 12396.3 24857.1 14335.0 11272.6 32306.8 38565.9  9194.7  9957.8  4071.6 15118.0  8769.5
IN 29500    1942 17835.1  9818.5 24258.1 24546.4  3753.5 21834.5 17842.4 10464.3 14700.4  4355.9  3832.9  4327.6
IN 29500    1943 16592.2  8898.8 10089.5 10705.9  5031.1     0.0 25255.9  8249.7  4348.3  2583.9  4487.0  8186.9
IN 29500    1944 29612.3 27949.4 27417.4 33099.7 59159.9 42274.5  7934.7  4744.4  7158.9  4880.5  6474.4 23862.8
```

c) An Example of FLO file

## 6.4 Comparative Evaluation of Disaggregated Daily Flows

WAM monthly naturalized flows are disaggregated based on SWAT generated daily pattern hydrographs while maintaining the monthly volumes. Even though daily flow sequences disaggregated from WAM monthly naturalized flows are not perfectly identical to the daily naturalized flow sequences generated with SWAT, they should have similar flow timing, flow regimes, and hydrological characteristics. The four different previously described methods are applied to evaluate two different disaggregated daily flow sequences: (1) disaggregated based daily flow pattern that is generated by the daily SWAT model calibrated with monthly naturalized flows (called “MDNF”), and (2) disaggregated based daily flow pattern that is generated by the daily SWAT model calibrated with USGS daily recorded flows (called “DDNF”), comparing with USGS daily recorded flows for the periods that are considered under practically naturalized conditions mentioned in the Section 6.2.2. The higher scored calibration strategy, summed up from the four different evaluation methods, is finally selected as the strategy to calibrate the daily SWAT model for synthesizing daily flow sequences.

The daily recorded flows at 6 gauges for the period from 1940 to 1960 for the Sabine WAM, at 7 gauges for the period from 1940 to 1960 for the Neches WAM, and 12 gauges for the period from different beginning years to 1960 for the GSA WAM are selected for the comparative evaluations for the reasons discussed in Section 6.2.2.

### 6.4.1 Sabine River Basin

NSE values of MDNF and DDNF are computed based on the USGS daily recorded flows for 21 years at 6 control points, and the comparative scores are made through the comparison of both NSE at a control point as listed in Table 6.10. NSE values of DDNF are higher at 3 control points, and lower at 2 control points than MDNF. Both NSE values are not acceptable levels at BSBS, so both performances are considered as the same. Total comparative scores are 5 for MDNF, and 7 for DDNF.

Table 6.10 Comparative Evaluation of Nash-Sutcliffe Efficiency for the Sabine WAM

| CP | Data Period | NSE | | Comparative Score | |
|---|---|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF | USGS vs. MDNF | USGS vs. DDNF |
| Total | | | | 5 | 7 |
| BSBS | 01/01/1940-12/31/1960 | -0.28 | -0.37 | 1 | 1 |
| LFQT | 01/01/1940-12/31/1960 | 0.28 | 0.33 | 0 | 2 |
| SRBE | 01/01/1940-12/31/1960 | 0.76 | 0.75 | 2 | 0 |
| SRGW | 01/01/1940-12/31/1960 | 0.74 | 0.69 | 2 | 0 |
| SRRL | 01/01/1940-12/31/1960 | 0.73 | 0.83 | 0 | 2 |
| SRBW | 01/01/1940-12/31/1960 | 0.79 | 0.86 | 0 | 2 |

The three different flow frequency metrics of USGS daily recorded flows, MDNF, and DDNF at 6 control points are tabulated in Tables 6.11 and 6.12. Both mean flows of MDNF and DDNF are very similar to the mean flows of USGS daily recorded flows at 6 control points. Both median (50% exceedance frequency) values of the MDCF and DDNF are also closely similar to the median values of USGS daily recorded flows at 6 control points. Maximum values of USGS daily recorded flows are much higher than both the value of MDNF and DDNF at 6 control points. Flow frequency metrics indicate that maximum values of MDNF are mostly higher than the value of DDNF, but minimum values of DDNF are more similar to the value of USGS daily recorded flows than MDNF.

Table 6.11 Flow Frequency Metrics for Control Points BSBS, LFQT, and SRBE

| | BSBS (CFS) | | | LFQT (CFS) | | | SRBE (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 203.2 | 202.4 | 202.4 | 480.7 | 480.6 | 480.6 | 2,789 | 2,883 | 2,883 |
| Std Dev | 479.4 | 404.2 | 426.6 | 1,921 | 1,335 | 1,197 | 5,430 | 5,040 | 4,814 |
| Min | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 0.0 | 1.1 |
| Max | 17,900 | 7,028 | 8,535 | 70,508 | 26,755 | 21,526 | 120,000 | 60,570 | 51,732 |
| 0.1% | 6,033 | 4,912 | 5,237 | 22,651 | 16,762 | 14,587 | 65,059 | 52,139 | 45,049 |
| 0.2% | 4,560 | 3,742 | 3,812 | 17,258 | 12,342 | 10,491 | 49,125 | 43,774 | 40,609 |
| 0.5% | 2,879 | 2,767 | 2,723 | 12,429 | 9,504 | 7,486 | 33,420 | 32,157 | 31,710 |
| 1% | 1,870 | 1,939 | 1,990 | 7,723 | 6,908 | 5,879 | 24,528 | 25,922 | 24,869 |
| 2% | 1,236 | 1,339 | 1,351 | 4,776 | 4,413 | 4,235 | 17,000 | 18,306 | 18,426 |
| 5% | 684.4 | 769.9 | 813 | 2,140 | 2,120 | 2,213 | 10,300 | 11,105 | 11,091 |
| 10% | 429.0 | 514.7 | 518 | 996.0 | 1,179.0 | 1,266 | 7,040 | 7,378 | 7,294 |
| 15% | 309.2 | 361.4 | 348.5 | 584.0 | 794.0 | 851.0 | 5,372 | 5,400 | 5,426 |
| 20% | 246.0 | 267.0 | 254.9 | 360.0 | 555.0 | 593.0 | 4,260 | 4,114 | 4,168 |
| 30% | 176.0 | 167.2 | 161.8 | 154.0 | 267.0 | 298.0 | 2,554 | 2,732 | 2,809 |
| 40% | 128.0 | 109.8 | 103.4 | 80.0 | 129.0 | 144.0 | 1,620 | 1,727 | 1,765 |
| 50% | 87.0 | 73.6 | 68.7 | 40.0 | 58.0 | 69.0 | 984.0 | 1,081 | 1,119 |
| 60% | 61.0 | 50.3 | 45.4 | 20.0 | 23.0 | 30.0 | 600.0 | 719.0 | 745.0 |
| 70% | 42.0 | 31.6 | 30.3 | 8.0 | 11.0 | 14.0 | 378.0 | 429.0 | 450.0 |
| 80% | 30.0 | 17.8 | 16.9 | 2.0 | 3.0 | 4.0 | 210.0 | 225.0 | 254.0 |
| 85% | 24.0 | 12.0 | 12.0 | 1.0 | 1.0 | 2.0 | 149.0 | 148.0 | 179.0 |
| 90% | 20.0 | 6.2 | 7.1 | 0.0 | 0.0 | 0.0 | 96.0 | 95.0 | 115.0 |
| 95% | 15.0 | 0.2 | 1.8 | 0.0 | 0.0 | 0.0 | 54.0 | 41.0 | 68.0 |
| 98% | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.0 | 7.0 | 20.0 |
| 99% | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 14.0 | 0.0 | 10.0 |
| 99.5% | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.0 | 0.0 | 5.0 |
| 99.8% | 6.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 0.0 | 2.0 |
| 99.9% | 6.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 0.0 | 1.0 |

Table 6.12 Flow Frequency Metrics for Control Points SRBW, SRGW and SRRL

| | SRBW (CFS) | | | SRGW (CFS) | | | SRRL (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 7,596 | 7,615 | 7,615 | 2,230 | 2,244 | 2,244 | 9,659 | 9,678 | 9,678 |
| Std Dev | 9,818 | 9,897 | 9,456 | 5,242 | 4,435 | 4,158 | 11,617 | 11,843 | 11,186 |
| Min | 160.0 | 77.6 | 121.0 | 6.1 | 0.0 | 2.0 | 270.0 | 139.4 | 211 |
| Max | 111,012 | 108,730 | 117,262 | 133,000 | 63,054 | 55,313 | 120,000 | 132,360 | 109,083 |
| 0.1% | 75,508 | 71,717 | 75,215 | 58,056 | 42,297 | 36,338 | 84,058 | 92,341 | 86,341 |
| 0.2% | 68,692 | 68,777 | 64,804 | 48,631 | 36,978 | 32,341 | 77,481 | 86,344 | 78,246 |
| 0.5% | 52,070 | 57,417 | 55,272 | 36,012 | 29,576 | 28,043 | 62,720 | 71,531 | 63,437 |
| 1% | 43,461 | 49,409 | 45,524 | 22,828 | 22,671 | 21,681 | 52,900 | 57,050 | 53,501 |
| 2% | 36,604 | 37,682 | 36,164 | 15,956 | 16,322 | 15,888 | 43,900 | 46,311 | 43,976 |
| 5% | 27,243 | 27,029 | 25,707 | 8,588 | 9,308 | 9,290 | 33,100 | 32,497 | 31,126 |
| 10% | 20,502 | 19,094 | 18,980 | 5,650 | 5,543 | 5,675 | 24,200 | 22,804 | 22,879 |
| 15% | 16,302 | 14,869 | 14,963 | 4,040 | 3,915 | 4,028 | 19,700 | 18,467 | 18,438 |
| 20% | 12,802 | 12,234 | 12,636 | 2,940 | 3,020 | 3,160 | 16,200 | 15,580 | 15,854 |
| 30% | 8,661 | 8,397 | 8,636 | 1,730 | 1,926 | 1,995 | 11,500 | 11,021 | 11,381 |
| 40% | 5,531 | 5,869 | 6,135 | 1,010 | 1,197 | 1,244 | 7,580 | 7,853 | 8,142 |
| 50% | 3,480 | 3,829 | 4,012 | 610.0 | 710.0 | 758.0 | 4,790 | 5,274 | 5,520 |
| 60% | 2,210 | 2,622 | 2,736 | 372.0 | 434.0 | 460.0 | 3,280 | 3,723 | 3,843 |
| 70% | 1,480 | 1,703 | 1,831 | 233.0 | 237.0 | 264.0 | 2,340 | 2,614 | 2,804 |
| 80% | 1,000 | 1,081 | 1,173 | 126.0 | 116.0 | 139.0 | 1,590 | 1,713 | 1,869 |
| 85% | 760.0 | 804.0 | 880.0 | 90.0 | 78.0 | 92.0 | 1,300 | 1,348 | 1,464 |
| 90% | 552.0 | 558.0 | 597.0 | 57.0 | 47.0 | 55.0 | 968.0 | 987.0 | 1,009 |
| 95% | 390.0 | 311.0 | 356.0 | 33.0 | 18.0 | 28.0 | 590.0 | 604.0 | 629.0 |
| 98% | 246.0 | 201.0 | 236.0 | 14.0 | 4.0 | 14.0 | 390.0 | 357.0 | 378.0 |
| 99% | 213.0 | 167.0 | 188.0 | 11.0 | 0.0 | 9.0 | 332.0 | 281.0 | 320.0 |
| 99.5% | 188.0 | 130.0 | 158.0 | 9.0 | 0.0 | 5.0 | 299.0 | 229.0 | 264.0 |
| 99.8% | 179.0 | 103.0 | 140.0 | 8.0 | 0.0 | 4.0 | 277.0 | 188.0 | 240.0 |
| 99.9% | 168.0 | 96.0 | 136.0 | 7.0 | 0.0 | 3.0 | 270.0 | 161.0 | 225.0 |

Table 6.13 summarizes the comparative scores, made through the qualitative comparison of both flow frequency metrics at a control point based on the USGS flows.

Table 6.13 Comparative Evaluation of Flow Frequency Metrics for the Sabine WAM

| CP | Data Period | Comparative Score USGS vs. MDNF | Comparative Score USGS vs. DDNF |
|---|---|---|---|
| Total | | 6 | 6 |
| BSBS | 01/01/1940-12/31/1960 | 1 | 1 |
| LFQT | 01/01/1940-12/31/1960 | 1 | 1 |
| SRBE | 01/01/1940-12/31/1960 | 1 | 1 |
| SRGW | 01/01/1940-12/31/1960 | 1 | 1 |
| SRRL | 01/01/1940-12/31/1960 | 1 | 1 |
| SRBW | 01/01/1940-12/31/1960 | 1 | 1 |

The DHRAM method quantitatively evaluates how much the hydrologic characteristics of MDNF and DDNF are similar to or different from USGS daily recorded flows at the 6 control points. The score ranges from 0 (almost identical) to 30 (totally different). Table 6.14 summarizes the scores of MDNF and DDNF based on the USGS daily recorded flows at the six points. Table 6.14 indicates that both MDNF and DDNF have nearly similar hydrological characteristics to USGS daily recorded flows at the 5 control points except for BSBS. At BSBS, DDNF has less impact points than NDNF. This means hydrological characteristics of DDNF are relatively more identical to USGS daily recorded flows. The detailed evaluation sheets for the six control points are tabulated in Tables 6.15 to 6.20.

Table 6.14 Impact Points by the DHRAM Method for the Sabine WAM

| CP | Data Period | Impact Points USGS vs. MDNF | Impact Points USGS vs. DDNF |
|---|---|---|---|
| Total | | 14 | 8 |
| BSBS | 01/01/1940-12/31/1960 | 9 | 5 |
| LFQT | 01/01/1940-12/31/1960 | 2 | 2 |
| SRBE | 01/01/1940-12/31/1960 | 1 | 0 |
| SRGW | 01/01/1940-12/31/1960 | 0 | 0 |
| SRRL | 01/01/1940-12/31/1960 | 1 | 0 |
| SRBW | 01/01/1940-12/31/1960 | 1 | 1 |

Table 6.15 indicates that the daily maximum and minimum flows of NDMF and DDMF are similar to the USGS daily recorded flows according to the results of parameter group #2, but the flow timings of both MDNF and DDNF are slightly different from the USGS daily recorded flows according to the results of parameter group #3.

Table 6.15 Evaluation Sheet by DHRAM Method for Control Point BSBS

Control Point: BSBS Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 267.9 | 0.7853 | 267.8 | 0.7857 | | 0.0% | 0.1% | 267.8 | 0.7857 | | 0.0% | 0.1% |
| February | 291.9 | 0.7031 | 291.8 | 0.7034 | | 0.0% | 0.0% | 291.8 | 0.7034 | | 0.0% | 0.0% |
| March | 324.7 | 1.077 | 324.6 | 1.078 | | 0.0% | 0.1% | 324.6 | 1.078 | | 0.0% | 0.1% |
| April | 371.3 | 0.8473 | 371.2 | 0.8474 | | 0.0% | 0.0% | 371.2 | 0.8474 | | 0.0% | 0.0% |
| May | 385.2 | 0.8235 | 385.1 | 0.8238 | | 0.0% | 0.0% | 385.1 | 0.8238 | | 0.0% | 0.0% |
| June | 213.3 | 1.054 | 204.8 | 0.9805 | | 4.0% | 7.0% | 204.8 | 0.9805 | | 4.0% | 7.0% |
| July | 76.97 | 0.8591 | 76.87 | 0.8608 | | 0.1% | 0.2% | 76.87 | 0.8608 | | 0.1% | 0.2% |
| August | 40.77 | 0.6854 | 40.67 | 0.6877 | | 0.2% | 0.3% | 40.67 | 0.6876 | | 0.2% | 0.3% |
| September | 44.86 | 0.6256 | 44.76 | 0.6268 | | 0.2% | 0.2% | 44.75 | 0.6268 | | 0.2% | 0.2% |
| October | 82.09 | 1.364 | 82 | 1.365 | | 0.1% | 0.1% | 82 | 1.365 | | 0.1% | 0.1% |
| November | 133.4 | 1.273 | 133.3 | 1.274 | | 0.1% | 0.1% | 133.3 | 1.274 | | 0.1% | 0.1% |
| December | 211.9 | 0.7568 | 211.8 | 0.7571 | | 0.0% | 0.0% | 211.8 | 0.7571 | | 0.0% | 0.0% |
| | | | | | Average | 0.4% | 0.7% | | | Average | 0.4% | 0.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 17.9 | 0.4326 | 1.519 | 1.867 | | 91.5% | 331.6% | 4.886 | 1.419 | | 72.7% | 228.0% |
| 3-day minimum | 18.16 | 0.4441 | 2.179 | 1.76 | | 88.0% | 296.3% | 5.43 | 1.387 | | 70.1% | 212.3% |
| 7-day minimum | 19.18 | 0.4482 | 4.259 | 1.907 | | 77.8% | 325.5% | 6.416 | 1.268 | | 66.5% | 182.9% |
| 30-day minimum | 23.29 | 0.4707 | 16.87 | 0.9111 | | 27.6% | 93.6% | 19.03 | 0.7465 | | 18.3% | 58.6% |
| 90-day minimum | 42.24 | 0.6288 | 38.91 | 0.6266 | | 7.9% | 0.3% | 40.05 | 0.6484 | | 5.2% | 3.1% |
| 1-day maximum | 4100 | 0.9947 | 2652 | 0.6787 | | 35.3% | 31.8% | 2817 | 0.7082 | | 31.3% | 28.8% |
| 3-day maximum | 3100 | 0.8816 | 2290 | 0.7188 | | 26.1% | 18.5% | 2423 | 0.754 | | 21.8% | 14.5% |
| 7-day maximum | 1979 | 0.8089 | 1654 | 0.7392 | | 16.4% | 8.6% | 1710 | 0.7533 | | 13.6% | 6.9% |
| 30-day maximum | 778.9 | 0.6413 | 744.5 | 0.5676 | | 4.4% | 11.5% | 737.7 | 0.5641 | | 5.3% | 12.0% |
| 90-day maximum | 436.2 | 0.5453 | 430.9 | 0.5309 | | 1.2% | 2.6% | 432.7 | 0.5312 | | 0.8% | 2.6% |
| | | | | | Average | 37.6% | 112.0% | | | Average | 30.6% | 75.0% |
| | | | | | Score | 0 | 1 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 230.3 | 0.06167 | 170.8 | 0.2212 | | 25.8% | 258.7% | 159.8 | 0.298 | | 30.6% | 383.2% |
| Date of maximum | 123 | 0.2319 | 123.1 | 0.197 | | 0.1% | 15.0% | 124 | 0.2546 | | 0.8% | 9.8% |
| | | | | | Average | 13.0% | 136.9% | | | Average | 15.7% | 196.5% |
| | | | | | Score | 1 | 3 | | | Score | 1 | 3 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4.667 | 0.5175 | 9.952 | 0.4221 | | 113.2% | 18.4% | 10.05 | 0.504 | | 115.3% | 2.6% |
| Low pulse duration | 23.95 | 0.8958 | 9.253 | 0.5219 | | 61.4% | 41.7% | 8.456 | 0.4832 | | 64.7% | 46.1% |
| High pulse count | 4.238 | 0.8372 | 6.429 | 0.4656 | | 51.7% | 44.4% | 6.143 | 0.5406 | | 45.0% | 35.4% |
| High pulse duration | 4.547 | 0.4597 | 4.25 | 0.3725 | | 6.5% | 19.0% | 4.301 | 0.3313 | | 5.4% | 27.9% |
| | | | | | Average | 58.2% | 30.9% | | | Average | 57.6% | 28.0% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 90.34 | 0.7494 | 118.4 | 0.689 | | 31.1% | 8.1% | 135.5 | 0.6574 | | 50.0% | 12.3% |
| Fall rate | -48.86 | -0.7086 | -40.79 | -0.562 | | 16.5% | 20.7% | -41.74 | -0.6154 | | 14.6% | 13.2% |
| Number of reversals | 75.19 | 0.09153 | 96.9 | 0.2916 | | 28.9% | 218.6% | 87 | 0.1808 | | 15.7% | 97.5% |
| | | | | | Average | 25.5% | 82.4% | | | Average | 26.8% | 41.0% |
| | | | | | Score | 0 | 2 | | | Score | 0 | 0 |

| | MDNF | | DDNF | |
|---|---|---|---|---|
| Total Point | | 9 | | 5 |
| Classification | | 3 | | 3 |
| note: | Moderate risk of impact | | Moderate risk of impact | |

Table 6.16 indicates that the amount of daily maximum and minimum flows of NDMF and DDMF are almost identical to the USGS daily recorded flows according to the results of parameter group # 2, but the flow timings of both MDNF and DDNF are also slightly different from the USGS daily recorded flows according to the results of parameter group #3.

Table 6.16 Evaluation Sheet by DHRAM Method for Control Point LFQT

Control Point: LFQT Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 509.9 | 1.048 | 509.8 | 1.048 | | 0.0% | 0.0% | 509.8 | 1.048 | | 0.0% | 0.0% |
| February | 707.1 | 1.147 | 707 | 1.148 | | 0.0% | 0.1% | 707 | 1.148 | | 0.0% | 0.1% |
| March | 765.6 | 1.73 | 765.4 | 1.73 | | 0.0% | 0.0% | 765.4 | 1.73 | | 0.0% | 0.0% |
| April | 1059 | 1.155 | 1059 | 1.155 | | 0.0% | 0.0% | 1059 | 1.155 | | 0.0% | 0.0% |
| May | 1067 | 0.9239 | 1067 | 0.9239 | | 0.0% | 0.0% | 1067 | 0.9239 | | 0.0% | 0.0% |
| June | 541.7 | 1.456 | 541.6 | 1.456 | | 0.0% | 0.0% | 541.6 | 1.456 | | 0.0% | 0.0% |
| July | 137.6 | 1.717 | 137.5 | 1.717 | | 0.1% | 0.0% | 137.5 | 1.717 | | 0.1% | 0.0% |
| August | 23.68 | 1.409 | 23.62 | 1.414 | | 0.3% | 0.4% | 23.62 | 1.414 | | 0.3% | 0.4% |
| September | 46.4 | 1.234 | 46.34 | 1.235 | | 0.1% | 0.1% | 46.34 | 1.235 | | 0.1% | 0.1% |
| October | 193.9 | 2.024 | 193.8 | 2.025 | | 0.1% | 0.0% | 193.8 | 2.025 | | 0.1% | 0.0% |
| November | 290.5 | 2.025 | 290.3 | 2.026 | | 0.1% | 0.0% | 290.3 | 2.026 | | 0.1% | 0.0% |
| December | 449.4 | 1.3 | 449.3 | 1.3 | | 0.0% | 0.0% | 449.3 | 1.3 | | 0.0% | 0.0% |
| | | | | | Average | 0.1% | 0.1% | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 0.3857 | 3.723 | 0.2 | 2.329 | | 48.1% | 37.4% | 0.491 | 2.721 | | 27.3% | 26.9% |
| 3-day minimum | 0.419 | 3.653 | 0.2444 | 2.197 | | 41.7% | 39.9% | 0.5848 | 2.384 | | 39.6% | 34.7% |
| 7-day minimum | 0.4898 | 3.365 | 0.4204 | 1.829 | | 14.2% | 45.6% | 0.7693 | 2.131 | | 57.1% | 36.7% |
| 30-day minimum | 1.561 | 1.802 | 2.057 | 1.505 | | 31.8% | 16.5% | 2.701 | 1.842 | | 73.0% | 2.2% |
| 90-day minimum | 29.31 | 1.748 | 28.75 | 1.64 | | 1.9% | 6.2% | 29.92 | 1.528 | | 2.1% | 12.6% |
| 1-day maximum | 17550 | 0.8863 | 10310 | 0.6656 | | 41.3% | 24.9% | 8289 | 0.6547 | | 52.8% | 26.1% |
| 3-day maximum | 12510 | 0.7942 | 7744 | 0.667 | | 38.1% | 16.0% | 6682 | 0.7048 | | 46.6% | 11.3% |
| 7-day maximum | 7414 | 0.775 | 5671 | 0.6983 | | 23.5% | 9.9% | 5223 | 0.6872 | | 29.6% | 11.3% |
| 30-day maximum | 2574 | 0.6791 | 2517 | 0.6513 | | 2.2% | 4.1% | 2482 | 0.6505 | | 3.6% | 4.2% |
| 90-day maximum | 1245 | 0.6593 | 1218 | 0.6599 | | 2.2% | 0.1% | 1215 | 0.66 | | 2.4% | 0.1% |
| | | | | | Average | 24.5% | 20.1% | | | Average | 33.4% | 16.6% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 226.2 | 0.09738 | 205.1 | 0.1589 | | 9.3% | 63.2% | 222.4 | 0.1737 | | 1.7% | 78.4% |
| Date of maximum | 158.7 | 0.3034 | 132.4 | 0.2798 | | 16.6% | 7.8% | 140.9 | 0.313 | | 11.2% | 3.2% |
| | | | | | Average | 13.0% | 35.5% | | | Average | 6.4% | 40.8% |
| | | | | | Score | 1 | 1 | | | Score | 0 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.905 | 0.4278 | 5.714 | 0.4635 | | 46.3% | 8.3% | 5.238 | 0.4307 | | 34.1% | 0.7% |
| Low pulse duration | 25.01 | 0.5855 | 17.22 | 0.7639 | | 31.1% | 30.5% | 18.65 | 0.7648 | | 25.4% | 30.6% |
| High pulse count | 4.81 | 0.5976 | 4.952 | 0.5511 | | 3.0% | 7.8% | 4 | 0.6423 | | 16.8% | 7.5% |
| High pulse duration | 3.202 | 0.3225 | 4.266 | 0.3714 | | 33.2% | 15.2% | 6.569 | 0.4252 | | 105.2% | 31.8% |
| | | | | | Average | 28.4% | 15.4% | | | Average | 45.4% | 17.7% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 452.2 | 0.6536 | 420.4 | 0.5262 | | 7.0% | 19.5% | 265.5 | 0.5348 | | 41.3% | 18.2% |
| Fall rate | -211.8 | -0.6301 | -128.6 | -0.5901 | | 39.3% | 6.3% | -93.86 | -0.6017 | | 55.7% | 4.5% |
| Number of reversals | 61.81 | 0.2046 | 73.67 | 0.1587 | | 19.2% | 22.4% | 70.57 | 0.1615 | | 14.2% | 21.1% |
| | | | | | Average | 21.8% | 16.1% | | | Average | 37.0% | 14.6% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| MDNF | | DDNF | |
|---|---|---|---|
| Total Point | 2 | Total Point | 2 |
| Classification | 2 | Classification | 2 |
| note: | Low risk of impact | note: | Low risk of impact |

The four other detailed evaluation sheets show that hydrologic characteristics of both NDMF and DDMF are almost identical to the USGS daily recorded flows as listed in Tables 6.17, 6.18, 6.19, and 6.20, respectively.

Table 6.17 Evaluation Sheet by DHRAM Method for Control Point SRBE

Control Point: SRBE Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDMF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 3241 | 0.8776 | 3327 | 0.8777 | | 2.7% | 0.0% | 3327 | 0.8777 | | 2.7% | 0.0% |
| February | 3649 | 0.885 | 3744 | 0.8862 | | 2.6% | 0.1% | 3744 | 0.8862 | | 2.6% | 0.1% |
| March | 3863 | 0.8817 | 3971 | 0.8796 | | 2.8% | 0.2% | 3971 | 0.8796 | | 2.8% | 0.2% |
| April | 4653 | 1.296 | 4786 | 1.294 | | 2.9% | 0.2% | 4786 | 1.294 | | 2.9% | 0.2% |
| May | 6831 | 0.9596 | 7017 | 0.958 | | 2.7% | 0.2% | 7017 | 0.958 | | 2.7% | 0.2% |
| June | 4149 | 1.127 | 4277 | 1.121 | | 3.1% | 0.5% | 4277 | 1.121 | | 3.1% | 0.5% |
| July | 1074 | 1.33 | 1114 | 1.313 | | 3.7% | 1.3% | 1114 | 1.313 | | 3.7% | 1.3% |
| August | 455.8 | 1.224 | 486.4 | 1.168 | | 6.7% | 4.6% | 486.4 | 1.168 | | 6.7% | 4.6% |
| September | 432.9 | 0.8049 | 463.1 | 0.7802 | | 7.0% | 3.1% | 463.1 | 0.7802 | | 7.0% | 3.1% |
| October | 776.8 | 1.312 | 814.9 | 1.286 | | 4.9% | 2.0% | 814.9 | 1.286 | | 4.9% | 2.0% |
| November | 1894 | 1.556 | 1955 | 1.546 | | 3.2% | 0.6% | 1955 | 1.546 | | 3.2% | 0.6% |
| December | 2527 | 1.075 | 2714 | 1.16 | | 7.4% | 7.9% | 2714 | 1.16 | | 7.4% | 7.9% |
| | | | | | Average | 4.1% | 1.7% | | | Average | 4.1% | 1.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 80.32 | 0.6394 | 24.1 | 1.226 | | 70.0% | 91.7% | 57.24 | 0.8438 | | 28.7% | 32.0% |
| 3-day minimum | 83.82 | 0.6599 | 27.77 | 1.173 | | 66.9% | 77.8% | 61.56 | 0.8239 | | 26.6% | 24.9% |
| 7-day minimum | 90.89 | 0.6885 | 38.99 | 1.032 | | 57.1% | 49.9% | 73.94 | 0.7998 | | 18.6% | 16.2% |
| 30-day minimum | 149.2 | 0.8329 | 136.2 | 0.7864 | | 8.7% | 5.6% | 157.7 | 0.7562 | | 5.7% | 9.2% |
| 90-day minimum | 379.9 | 0.8972 | 396.6 | 0.8344 | | 4.4% | 7.0% | 403.3 | 0.8229 | | 6.2% | 8.3% |
| 1-day maximum | 29820 | 0.9388 | 21970 | 0.6859 | | 26.3% | 26.9% | 19980 | 0.6657 | | 33.0% | 29.1% |
| 3-day maximum | 28130 | 0.9338 | 21440 | 0.6989 | | 23.8% | 25.2% | 19600 | 0.6776 | | 30.3% | 27.4% |
| 7-day maximum | 23270 | 0.8652 | 20000 | 0.7246 | | 14.1% | 16.3% | 18420 | 0.7068 | | 20.8% | 18.3% |
| 30-day maximum | 11890 | 0.6502 | 11810 | 0.6512 | | 0.7% | 0.2% | 11680 | 0.6527 | | 1.8% | 0.4% |
| 90-day maximum | 6529 | 0.6023 | 6692 | 0.5988 | | 2.5% | 0.6% | 6671 | 0.6002 | | 2.2% | 0.3% |
| | | | | | Average | 27.4% | 30.1% | | | Average | 17.4% | 16.6% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 258.1 | 0.07018 | 243.5 | 0.08581 | | 5.7% | 22.3% | 260.4 | 0.07874 | | 0.9% | 12.2% |
| Date of maximum | 152.7 | 0.2417 | 135.3 | 0.2111 | | 11.4% | 12.7% | 147.7 | 0.2345 | | 3.3% | 3.0% |
| | | | | | Average | 8.5% | 17.5% | | | Average | 2.1% | 7.6% |
| | | | | | Score | 1 | 0 | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.762 | 0.436 | 4.619 | 0.3717 | | 22.8% | 14.7% | 4 | 0.3708 | | 6.3% | 15.0% |
| Low pulse duration | 27.8 | 0.8351 | 22.54 | 0.8268 | | 18.9% | 1.0% | 25.47 | 0.7979 | | 8.4% | 4.5% |
| High pulse count | 2.381 | 0.7569 | 2.857 | 0.7112 | | 20.0% | 6.0% | 2.619 | 0.7961 | | 10.0% | 5.2% |
| High pulse duration | 11.78 | 0.5354 | 12.96 | 0.6537 | | 10.0% | 22.1% | 14.28 | 0.6199 | | 21.2% | 15.8% |
| | | | | | Average | 17.9% | 11.0% | | | Average | 11.5% | 10.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 463.9 | 0.6815 | 432.2 | 0.6254 | | 6.8% | 8.2% | 369.3 | 0.5944 | | 20.4% | 12.8% |
| Fall rate | -323.2 | -0.6393 | -263.1 | -0.5724 | | 18.6% | 10.5% | -239.7 | -0.581 | | 25.8% | 9.1% |
| Number of reversals | 61.81 | 0.1338 | 58.33 | 0.1114 | | 5.6% | 16.7% | 51.9 | 0.1496 | | 16.0% | 11.8% |
| | | | | | Average | 10.4% | 11.8% | | | Average | 20.8% | 11.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | MDNF | | DDMF | |
|---|---|---|---|---|
| Total Point | | 1 | | 0 |
| Classification | | 2 | | 1 |
| note: | Low risk of impact | | Un-impacted condition | |

## Table 6.18 Evaluation Sheet by DHRAM Method for Control Point SRBW

| Control Point: | SRBW | Data: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 10830 | 0.8497 | 10830 | 0.8491 | | 0.0% | 0.1% | 10830 | 0.8491 | | 0.0% | 0.1% |
| February | 12020 | 0.6104 | 12040 | 0.6083 | | 0.2% | 0.3% | 12040 | 0.6083 | | 0.2% | 0.3% |
| March | 11640 | 0.5854 | 11650 | 0.5834 | | 0.1% | 0.3% | 11650 | 0.5834 | | 0.1% | 0.3% |
| April | 11380 | 0.8222 | 11400 | 0.8192 | | 0.2% | 0.4% | 11400 | 0.8192 | | 0.2% | 0.4% |
| May | 15470 | 0.9463 | 15460 | 0.9454 | | 0.1% | 0.1% | 15460 | 0.9454 | | 0.1% | 0.1% |
| June | 9311 | 0.9261 | 9322 | 0.9239 | | 0.1% | 0.2% | 9322 | 0.9239 | | 0.1% | 0.2% |
| July | 3691 | 0.9961 | 3696 | 0.9937 | | 0.1% | 0.2% | 3696 | 0.9937 | | 0.1% | 0.2% |
| August | 1973 | 0.9887 | 1973 | 0.9866 | | 0.0% | 0.2% | 1973 | 0.9866 | | 0.0% | 0.2% |
| September | 1687 | 1.295 | 1711 | 1.297 | | 1.4% | 0.2% | 1711 | 1.297 | | 1.4% | 0.2% |
| October | 2031 | 1.146 | 2038 | 1.136 | | 0.3% | 0.9% | 2038 | 1.136 | | 0.3% | 0.9% |
| November | 4200 | 1.247 | 4212 | 1.24 | | 0.3% | 0.6% | 4212 | 1.24 | | 0.3% | 0.6% |
| December | 7173 | 1.184 | 7298 | 1.18 | | 1.7% | 0.3% | 7298 | 1.18 | | 1.7% | 0.3% |
| | | | | | Average | 0.4% | 0.3% | | | Average | 0.4% | 0.3% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 521.9 | 0.4928 | 333.9 | 0.7249 | | 36.0% | 47.1% | 420.2 | 0.6697 | | 19.5% | 35.9% |
| 3-day minimum | 533.8 | 0.5054 | 346.7 | 0.6963 | | 35.1% | 37.8% | 434.1 | 0.6617 | | 18.7% | 30.9% |
| 7-day minimum | 556.6 | 0.5163 | 378.3 | 0.6807 | | 32.0% | 31.8% | 465.2 | 0.6383 | | 16.4% | 23.6% |
| 30-day minimum | 743.6 | 0.6263 | 639.5 | 0.5798 | | 14.0% | 7.4% | 708.8 | 0.5832 | | 4.7% | 6.9% |
| 90-day minimum | 1271 | 0.7443 | 1293 | 0.7258 | | 1.7% | 2.5% | 1327 | 0.721 | | 4.4% | 3.1% |
| 1-day maximum | 39520 | 0.5873 | 46540 | 0.5991 | | 17.8% | 2.0% | 38870 | 0.655 | | 1.6% | 11.5% |
| 3-day maximum | 38320 | 0.5811 | 41230 | 0.5422 | | 7.6% | 6.7% | 36710 | 0.6024 | | 4.2% | 3.7% |
| 7-day maximum | 35390 | 0.5661 | 36330 | 0.5403 | | 2.7% | 4.6% | 33740 | 0.5792 | | 4.7% | 2.3% |
| 30-day maximum | 25360 | 0.5646 | 25290 | 0.5841 | | 0.3% | 3.5% | 25030 | 0.5904 | | 1.3% | 4.6% |
| 90-day maximum | 16410 | 0.5032 | 16120 | 0.5021 | | 1.8% | 0.2% | 16090 | 0.5008 | | 2.0% | 0.5% |
| | | | | | Average | 14.9% | 14.4% | | | Average | 7.7% | 12.3% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 274.5 | 0.07505 | 270 | 0.09137 | | 1.6% | 21.7% | 275.4 | 0.0914 | | 0.3% | 21.8% |
| Date of maximum | 133.3 | 0.2469 | 124 | 0.257 | | 7.0% | 4.1% | 116.2 | 0.1866 | | 12.8% | 24.4% |
| | | | | | Average | 4.3% | 12.9% | | | Average | 6.6% | 23.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.905 | 0.4429 | 4.238 | 0.4772 | | 8.5% | 7.7% | 3.238 | 0.5066 | | 17.1% | 14.4% |
| Low pulse duration | 23.44 | 0.6546 | 22.19 | 0.4934 | | 5.3% | 24.6% | 33.23 | 0.729 | | 41.8% | 11.4% |
| High pulse count | 3.476 | 0.7199 | 4.048 | 0.7986 | | 16.5% | 10.9% | 2.81 | 0.7685 | | 19.2% | 6.8% |
| High pulse duration | 13.26 | 0.5882 | 9.765 | 0.4143 | | 26.4% | 29.6% | 14.74 | 0.674 | | 11.2% | 14.6% |
| | | | | | Average | 14.2% | 18.2% | | | Average | 22.3% | 11.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 1016 | 0.3919 | 1252 | 0.5498 | | 23.2% | 40.3% | 756.2 | 0.5587 | | 25.6% | 42.6% |
| Fall rate | -588.4 | -0.4064 | -667.7 | -0.5301 | | 13.5% | 30.4% | -461.3 | -0.5457 | | 21.6% | 34.3% |
| Number of reversals | 65.95 | 0.1252 | 71.57 | 0.1379 | | 8.5% | 10.1% | 58.05 | 0.1348 | | 12.0% | 7.7% |
| | | | | | Average | 15.1% | 27.0% | | | Average | 19.7% | 28.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Total Point | 0 | | Total Point | 0 | |
| Classification | 1 | | Classification | 1 | |
| note: | Un-impacted condition | | note: | Un-impacted condition | |

# Table 6.19 Evaluation Sheet by DHRAM Method for Control Point SRGW

Control Point: SRGW    Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 2380 | 0.8903 | 2381 | 0.8897 | | 0.0% | 0.1% | 2381 | 0.8897 | | 0.0% | 0.1% |
| February | 2891 | 1.063 | 2895 | 1.062 | | 0.1% | 0.1% | 2895 | 1.062 | | 0.1% | 0.1% |
| March | 2856 | 0.9502 | 2859 | 0.9487 | | 0.1% | 0.2% | 2859 | 0.9487 | | 0.1% | 0.2% |
| April | 4250 | 1.283 | 4253 | 1.281 | | 0.1% | 0.2% | 4253 | 1.281 | | 0.1% | 0.2% |
| May | 5273 | 0.9674 | 5277 | 0.9665 | | 0.1% | 0.1% | 5277 | 0.9665 | | 0.1% | 0.1% |
| June | 3585 | 1.213 | 3590 | 1.211 | | 0.1% | 0.2% | 3590 | 1.211 | | 0.1% | 0.2% |
| July | 716 | 1.268 | 722.1 | 1.256 | | 0.9% | 0.9% | 722.1 | 1.256 | | 0.9% | 0.9% |
| August | 298.6 | 1.278 | 305.4 | 1.249 | | 2.3% | 2.3% | 305.4 | 1.249 | | 2.3% | 2.3% |
| September | 314.3 | 0.8391 | 319.1 | 0.8242 | | 1.5% | 1.8% | 319.1 | 0.8242 | | 1.5% | 1.8% |
| October | 671.7 | 1.381 | 676.4 | 1.37 | | 0.7% | 0.8% | 676.4 | 1.37 | | 0.7% | 0.8% |
| November | 1512 | 1.698 | 1520 | 1.687 | | 0.5% | 0.6% | 1520 | 1.687 | | 0.5% | 0.6% |
| December | 2095 | 1.101 | 2211 | 1.176 | | 5.5% | 6.8% | 2211 | 1.176 | | 5.5% | 6.8% |
| | | | | | Average | 1.0% | 1.2% | | | Average | 1.0% | 1.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 48.85 | 0.6603 | 10.13 | 1.66 | | 79.3% | 151.4% | 26.52 | 0.992 | | 45.7% | 50.2% |
| 3-day minimum | 51.19 | 0.6683 | 11.84 | 1.596 | | 76.9% | 138.8% | 28.38 | 0.962 | | 44.6% | 43.9% |
| 7-day minimum | 55.66 | 0.665 | 16.87 | 1.312 | | 69.7% | 97.3% | 33.18 | 0.9194 | | 40.4% | 38.3% |
| 30-day minimum | 98.69 | 0.8721 | 77.66 | 0.8928 | | 21.3% | 2.4% | 90.02 | 0.8494 | | 8.8% | 2.6% |
| 90-day minimum | 266.7 | 0.9217 | 258.8 | 0.8888 | | 3.0% | 3.6% | 266.7 | 0.8869 | | 0.0% | 3.8% |
| 1-day maximum | 31860 | 0.9299 | 22020 | 0.6617 | | 30.9% | 28.8% | 19530 | 0.6721 | | 38.7% | 27.7% |
| 3-day maximum | 29460 | 0.8738 | 20770 | 0.6898 | | 29.5% | 21.1% | 18990 | 0.6703 | | 35.5% | 23.3% |
| 7-day maximum | 23880 | 0.8 | 19020 | 0.6938 | | 20.4% | 13.3% | 17430 | 0.6666 | | 27.0% | 16.7% |
| 30-day maximum | 10450 | 0.6428 | 10160 | 0.6199 | | 2.8% | 3.6% | 10050 | 0.6162 | | 3.8% | 4.1% |
| 90-day maximum | 5369 | 0.6237 | 5333 | 0.6185 | | 0.7% | 0.8% | 5312 | 0.6192 | | 1.1% | 0.7% |
| | | | | | Average | 33.4% | 46.1% | | | Average | 24.6% | 21.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 247.5 | 0.06392 | 230.1 | 0.1154 | | 7.0% | 80.5% | 259.7 | 0.0948 | | 4.9% | 48.3% |
| Date of maximum | 156.4 | 0.2839 | 165.7 | 0.2988 | | 5.9% | 5.2% | 160 | 0.2685 | | 2.3% | 5.4% |
| | | | | | Average | 6.5% | 42.9% | | | Average | 3.6% | 26.9% |
| | | | | | Score | 0 | 1 | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4.143 | 0.4337 | 4.81 | 0.3195 | | 16.1% | 26.3% | 4.619 | 0.3317 | | 11.5% | 23.5% |
| Low pulse duration | 23.29 | 0.7089 | 18.68 | 0.6144 | | 19.8% | 13.3% | 20.69 | 0.7459 | | 11.2% | 5.2% |
| High pulse count | 2.333 | 0.7706 | 2.619 | 0.7586 | | 12.3% | 1.6% | 2.286 | 0.6937 | | 2.0% | 10.0% |
| High pulse duration | 10.11 | 0.2896 | 12.32 | 0.5168 | | 21.9% | 78.5% | 15.33 | 0.5277 | | 51.6% | 82.2% |
| | | | | | Average | 17.5% | 29.9% | | | Average | 19.1% | 30.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 469.8 | 0.7136 | 453.1 | 0.595 | | 3.6% | 16.6% | 353.5 | 0.5526 | | 24.8% | 22.6% |
| Fall rate | -360.3 | -0.7137 | -265.2 | -0.5784 | | 26.4% | 19.0% | -218.1 | -0.5868 | | 39.5% | 17.8% |
| Number of reversals | 60.38 | 0.1572 | 60 | 0.2178 | | 0.6% | 38.5% | 51.86 | 0.1587 | | 14.1% | 1.0% |
| | | | | | Average | 10.2% | 24.7% | | | Average | 26.1% | 13.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| | | | | | | | | | | | | |
| | | | | Total Point | | 1 | | | Total Point | | 0 | |
| | | | | Classification | | 2 | | | Classification | | 1 | |
| | | | | note: | Low risk of impact | | | | note: | Un-impacted condition | | |

Table 6.20 Evaluation Sheet by DHRAM Method for Control Point SRRL

| Control Point: | SRRL | Period: | 1940-1960 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | Absolute Chages | | DDNF | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | |
| January | 13620 | 0.8126 | 13620 | 0.8121 | 0.0% | 0.1% | 13620 | 0.8121 | 0.0% | 0.1% |
| February | 15590 | 0.5655 | 15610 | 0.564 | 0.1% | 0.3% | 15610 | 0.564 | 0.1% | 0.3% |
| March | 14500 | 0.5446 | 14520 | 0.5431 | 0.1% | 0.3% | 14520 | 0.5431 | 0.1% | 0.3% |
| April | 14200 | 0.7736 | 14220 | 0.7714 | 0.1% | 0.3% | 14220 | 0.7714 | 0.1% | 0.3% |
| May | 17770 | 0.8819 | 17760 | 0.8812 | 0.1% | 0.1% | 17760 | 0.8812 | 0.1% | 0.1% |
| June | 11990 | 0.9279 | 12000 | 0.9263 | 0.1% | 0.2% | 12000 | 0.9263 | 0.1% | 0.2% |
| July | 5539 | 0.868 | 5544 | 0.8667 | 0.1% | 0.1% | 5544 | 0.8667 | 0.1% | 0.1% |
| August | 3138 | 1.034 | 3138 | 1.034 | 0.0% | 0.0% | 3138 | 1.034 | 0.0% | 0.0% |
| September | 2474 | 1.07 | 2498 | 1.073 | 1.0% | 0.3% | 2498 | 1.073 | 1.0% | 0.3% |
| October | 2713 | 1.108 | 2720 | 1.1 | 0.3% | 0.7% | 2720 | 1.1 | 0.3% | 0.7% |
| November | 5248 | 1.166 | 5261 | 1.16 | 0.2% | 0.5% | 5261 | 1.16 | 0.2% | 0.5% |
| December | 9488 | 1.108 | 9614 | 1.102 | 1.3% | 0.5% | 9614 | 1.102 | 1.3% | 0.5% |
| | | | | Average | 0.3% | 0.3% | | Average | 0.3% | 0.3% |
| | | | | Score | 0 | 0 | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | |
| 1-day minimum | 879.5 | 0.5008 | 672.9 | 0.6058 | 23.5% | 21.0% | 774.3 | 0.5588 | 12.0% | 11.6% |
| 3-day minimum | 893.6 | 0.5095 | 691.6 | 0.5983 | 22.6% | 17.4% | 793.1 | 0.5536 | 11.2% | 8.7% |
| 7-day minimum | 924.2 | 0.5145 | 740.2 | 0.5806 | 19.9% | 12.8% | 843.8 | 0.5493 | 8.7% | 6.8% |
| 30-day minimum | 1151 | 0.5563 | 1091 | 0.5113 | 5.2% | 8.1% | 1177 | 0.5195 | 2.3% | 6.6% |
| 90-day minimum | 1885 | 0.6383 | 1920 | 0.6344 | 1.9% | 0.6% | 1958 | 0.6298 | 3.9% | 1.3% |
| 1-day maximum | 47590 | 0.5207 | 58870 | 0.579 | 23.7% | 11.2% | 47830 | 0.5851 | 0.5% | 12.4% |
| 3-day maximum | 46460 | 0.5236 | 52620 | 0.5517 | 13.3% | 5.4% | 45550 | 0.583 | 2.0% | 11.3% |
| 7-day maximum | 43090 | 0.529 | 44760 | 0.5298 | 3.9% | 0.2% | 41130 | 0.5543 | 4.5% | 4.8% |
| 30-day maximum | 30540 | 0.5255 | 30250 | 0.5355 | 0.9% | 1.9% | 29850 | 0.5401 | 2.3% | 2.8% |
| 90-day maximum | 20090 | 0.4642 | 19750 | 0.4611 | 1.7% | 0.7% | 19710 | 0.4606 | 1.9% | 0.8% |
| | | | | Average | 11.7% | 7.9% | | Average | 4.9% | 6.7% |
| | | | | Score | 0 | 0 | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | |
| Date of minimum | 273 | 0.06876 | 263.8 | 0.08837 | 3.4% | 28.5% | 271.9 | 0.09043 | 0.4% | 31.5% |
| Date of maximum | 136.5 | 0.2536 | 135.1 | 0.2566 | 1.0% | 1.2% | 137.2 | 0.2452 | 0.5% | 3.3% |
| | | | | Average | 2.2% | 14.9% | | Average | 0.5% | 17.4% |
| | | | | Score | 0 | 0 | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | |
| Low pulse count | 3.238 | 0.6471 | 3.667 | 0.4076 | 13.2% | 37.0% | 2.905 | 0.5647 | 10.3% | 12.7% |
| Low pulse duration | 40.26 | 1.118 | 30.06 | 0.9182 | 25.3% | 17.9% | 41.88 | 0.8572 | 4.0% | 23.3% |
| High pulse count | 3.238 | 0.6322 | 4.238 | 0.7307 | 30.9% | 15.6% | 3.095 | 0.7071 | 4.4% | 11.8% |
| High pulse duration | 13.54 | 0.6896 | 9.354 | 0.6405 | 30.9% | 7.1% | 13.41 | 0.6548 | 1.0% | 5.0% |
| | | | | Average | 25.1% | 19.4% | | Average | 4.9% | 13.2% |
| | | | | Score | 0 | 0 | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | |
| Rise rate | 1123 | 0.38 | 1621 | 0.6093 | 44.3% | 60.3% | 1029 | 0.5861 | 8.4% | 54.2% |
| Fall rate | -721.9 | -0.3911 | -803.9 | -0.5558 | 11.4% | 42.1% | -565.4 | -0.5564 | 21.7% | 42.3% |
| Number of reversals | 48.86 | 0.07187 | 69.71 | 0.1699 | 42.7% | 136.4% | 54.14 | 0.1394 | 10.8% | 94.0% |
| | | | | Average | 32.8% | 79.6% | | Average | 13.6% | 63.5% |
| | | | | Score | 0 | 1 | | Score | 0 | 1 |
| | | | Total Point | | 1 | | Total Point | | 1 | |
| | | | Classification | | 2 | | Classification | | 2 | |
| | | | note: | Low risk of impact | | | note: | Low risk of impact | | |

Annual median flow duration curves represent the overall hydrologic state of a flow such as drought and flood years. Table 6.21 summarizes the comparative scores, made through the qualitative comparison of both annual median flow duration curves at a control point. Annual flow duration curves of each flow sequence at the six control points are as shown in Figures 6.4 to 6.9, respectively.

Table 6.21 Comparative Evaluation of Annual Median Flow Duration Curve for the Sabine WAM

| CP | Data Period | Comparative Score USGS vs. MDNF | USGS vs. DDNF |
|---|---|---|---|
| Total | | 6 | 6 |
| BSBS | 01/01/1940-12/31/1960 | 1 | 1 |
| LFQT | 01/01/1940-12/31/1960 | 1 | 1 |
| SRBE | 01/01/1940-12/31/1960 | 1 | 1 |
| SRGW | 01/01/1940-12/31/1960 | 1 | 1 |
| SRRL | 01/01/1940-12/31/1960 | 1 | 1 |
| SRBW | 01/01/1940-12/31/1960 | 1 | 1 |

Both the annual median flows of MDNF and DDNF at BSBS are underestimated compared to the median of USGS daily recorded flow, but both the disaggregated flows have proportionally similar hydrological state to the USGS flows as shown in Figure 6.4.

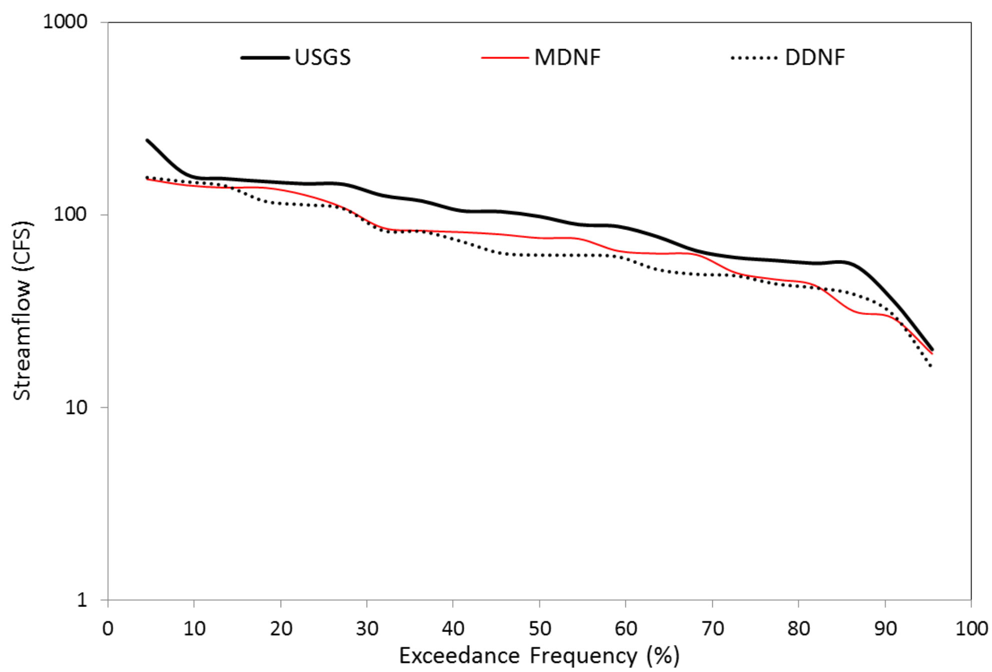



Figure 6.4 Annual Median Flow Duration Curves at BSBS

Both the annual median flows of MDNF and DDNF at LFQT are greater than the median of USGS daily recorded flow. Both the disaggregated flows particularly overestimated than the median of USGS daily recorded flow for relatively flood and normal years, but practically similar for relatively drought years as shown in Figure 6.5.

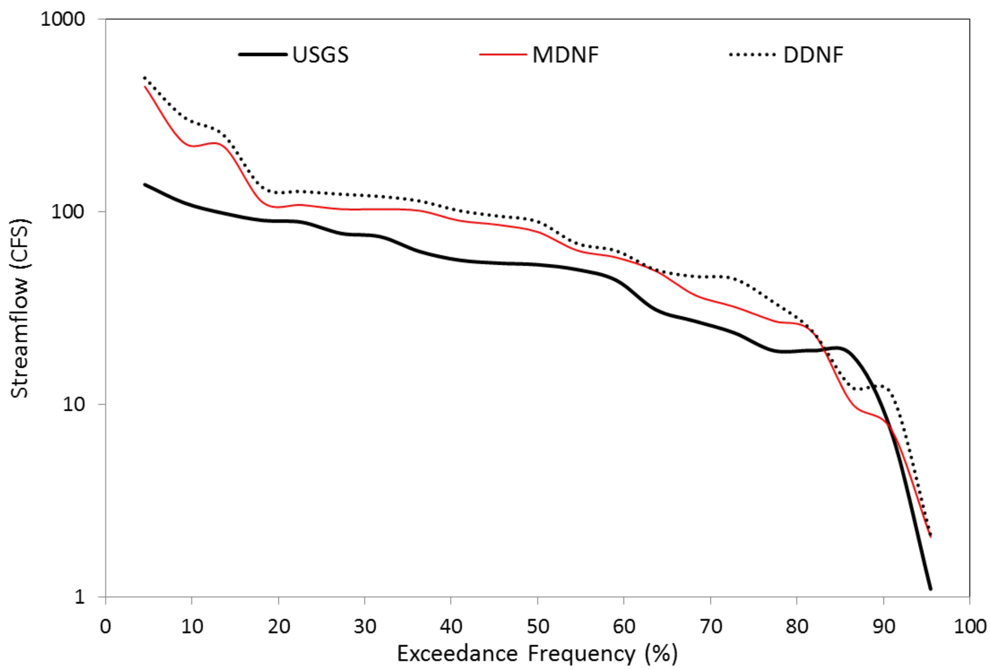



Figure 6.5 Annual Median Flow Duration Curves at LFQT

The annual median duration curves at other four control points are practically identical to one another even though both the annual median flows of MDNF and DDNF are slightly overestimated than the median of USGS daily recorded flow for relatively flood and normal years as shown in Figures 6.6 to 6.9.

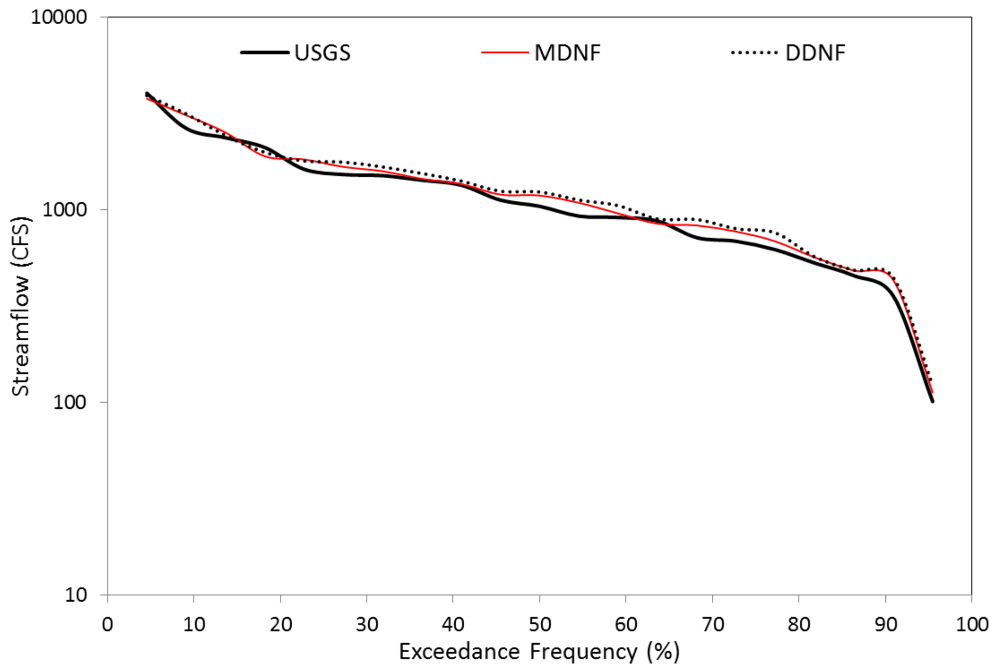



Figure 6.6 Annual Median Flow Duration Curves at SRBE

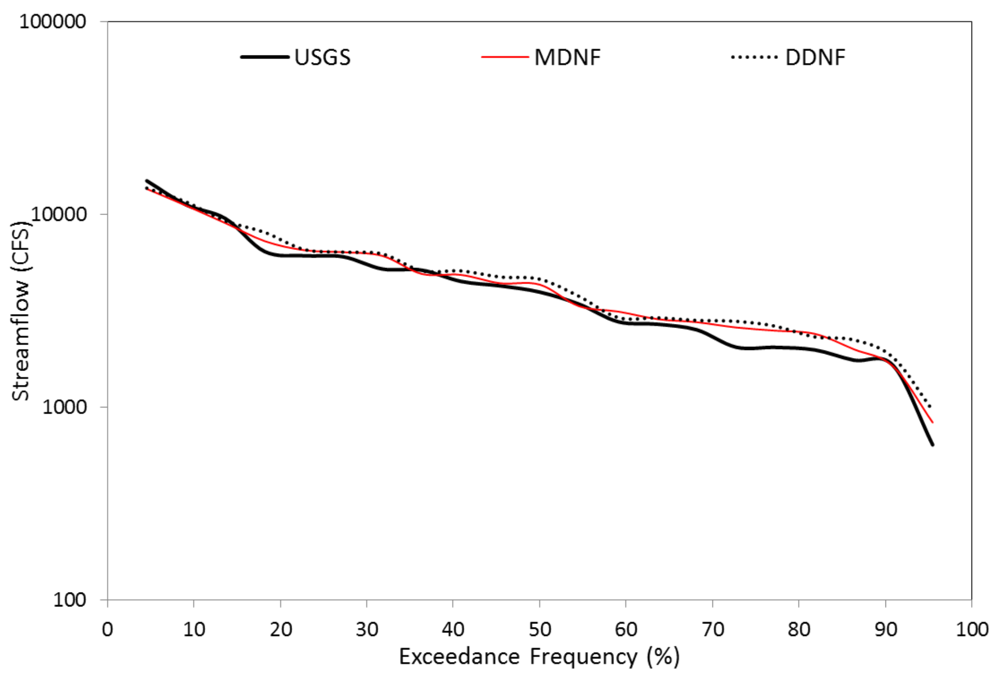



Figure 6.7 Annual Median Flow Duration Curves at SRBW

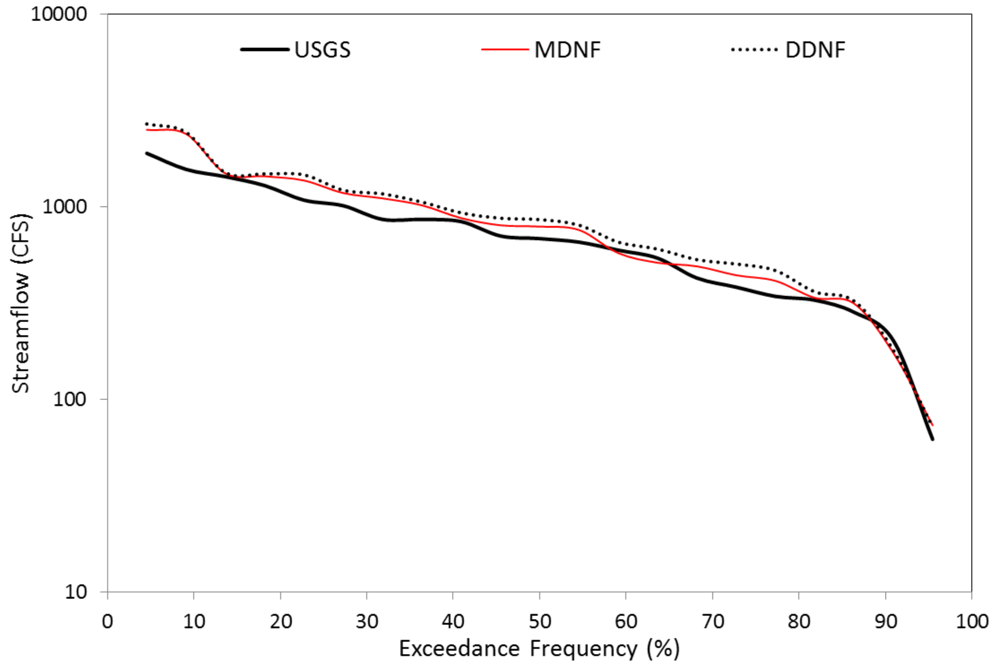



Figure 6.8 Annual Median Flow Duration Curves at SRGW

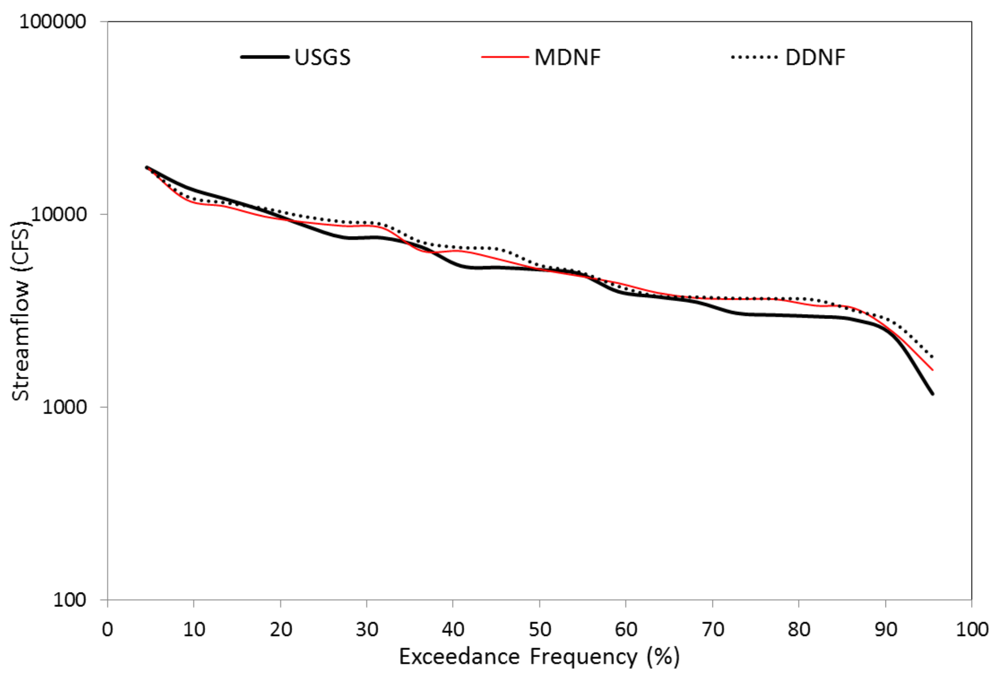



Figure 6.9 Annual Median Flow Duration Curves at SRRL

The calibration strategy with USGS daily recorded flows for the daily SWAT model to synthesize daily flow sequences at 21 control point for 1940-2013 is selected for the daily Sabine WAM as tabulated in Table 6.22. DDNF has better performances on statistic (NSE) and DHRAM evaluations than MDNF while both disaggregated daily flow sequences have similar performance on the qualitative evaluations, flow frequency metrics and median annual flow duration curves.

Table 6.22 Selection of calibration Strategy for the Sabine WAM

| Methods | Evaluation purposes | Calibration Strategy | |
|---|---|---|---|
| | | Monthly WAM datasets | Daily USGS recorded data |
| Total Score | | 2 | 6 |
| Statistic Evaluation (NSE) | Streamflow timing | 0 | 2 |
| Flow Frequency Metric | Streamflow regime | 1 | 1 |
| DHRAM (IHA) | Hydrologic characteristics alteration | 0 | 2 |
| Median Annual Flow Duration Curve | Overall hydrologic state of a river | 1 | 1 |

### 6.4.2 Neches River Basin

NSE values of MDNF and DDNF are computed based on the USGS recorded flows for 21 years at 7 control points, and the comparative scores are made through the comparison of both NSE at a control point as listed in Table 6.23. DDNF outperforms NDNF on NSE evaluation at all the 7 control points. Especially, NSE values of MDNF are not satisfied (NSE<0.5) at MUJA and VIKO, but NSE values of DDNF are satisfied at both same control points. Total comparative scores are 0 for MDNF, and 14 for DDNF.

Table 6.23 Comparative Evaluation of Nash-Sutcliff Efficiency for the Neches WAM

| CP | Data Period | NSE | | Comparative Score | |
|---|---|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF | USGS vs. MDNF | USGS vs. DDNF |
| Total | | | | 0 | 14 |
| MUJA | 01/01/1940-12/31/1960 | 0.33 | 0.58 | 0 | 2 |
| ANLU | 01/01/1940-12/31/1960 | 0.62 | 0.82 | 0 | 2 |
| NENE | 01/01/1940-12/31/1960 | 0.54 | 0.71 | 0 | 2 |
| NEDI | 01/01/1940-12/31/1960 | 0.60 | 0.84 | 0 | 2 |
| NERO | 01/01/1940-12/31/1960 | 0.56 | 0.88 | 0 | 2 |
| VIKO | 01/01/1940-12/31/1960 | 0.39 | 0.51 | 0 | 2 |
| NEEV | 01/01/1940-12/31/1960 | 0.66 | 0.90 | 0 | 2 |

The three different flow frequency metrics of USGS daily recorded flows, MDNF, and DDNF at 7 control points are tabulated in Tables 6.24, 6.25 and 6.26. Both mean flows of MDNF and DDNF are very similar to the mean flows of USGS daily recorded flows at all control points. Both median (50% exceedance frequency) values of the MDCF and DDNF are also closely similar to the median values of USGS daily recorded flows at all control points. However, maximum values of MDNF are mostly much higher than USGS daily recorded flows except for NENE. However, DDNF are mostly less than USGS daily recorded flows except for NEEV. These indicate that the flow regimes of MDNF are more variable than DDNF.

Table 6.24 Flow Frequency Metrics for Control Points MUJA, ANLU, and NENE

| | MUJA (CFS) | | | ANLU (CFS) | | | NENE (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 293.6 | 301.3 | 301.3 | 1,298 | 1,303 | 1,303 | 799.9 | 796.4 | 796.4 |
| Std Dev | 717.2 | 667.3 | 625.7 | 2,120 | 2,069 | 2,126 | 1,671 | 1,362 | 1,471 |
| Min | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| Max | 18,400 | 25,939 | 14,106 | 30,200 | 31,468 | 22,908 | 44,100 | 30,746 | 25,516 |
| 0.1% | 8,146 | 5,996 | 6,865 | 21,831 | 20,207 | 19,354 | 17,826 | 13,390 | 16,210 |
| 0.2% | 6,400 | 4,747 | 4,962 | 18,662 | 16,188 | 17,657 | 15,100 | 10,767 | 11,382 |
| 0.5% | 4,443 | 3,207 | 3,855 | 13,400 | 12,335 | 13,214 | 11,128 | 8,017 | 9,481 |
| 1% | 3,403 | 2,437 | 3,018 | 9,576 | 9,568 | 9,797 | 7,319 | 6,300 | 6,803 |
| 2% | 2,206 | 1,911 | 2,319 | 7,569 | 7,400 | 7,800 | 4,751 | 4,828 | 5,252 |
| 5% | 1,080 | 1,253 | 1,356 | 4,770 | 5,202 | 5,500 | 2,950 | 3,292 | 3,433 |
| 10% | 680.0 | 806.8 | 828.8 | 3,350 | 3,474 | 3,558 | 1,910 | 2,121 | 2,160 |
| 15% | 502.0 | 579.0 | 553.2 | 2,600 | 2,638 | 2,627 | 1,380 | 1,519 | 1,515 |
| 20% | 363.0 | 437.0 | 408.0 | 2,060 | 2,074 | 2,014 | 1,080 | 1,190 | 1,097 |
| 30% | 227.0 | 266.0 | 222.0 | 1,310 | 1,292 | 1,195 | 734.0 | 752.0 | 681.0 |
| 40% | 144.0 | 157.0 | 124.0 | 842.0 | 809.0 | 773.0 | 488.0 | 475.0 | 438.0 |
| 50% | 89.0 | 95.0 | 75.0 | 508.0 | 498.0 | 478.0 | 320.0 | 312.0 | 280.0 |
| 60% | 56.0 | 59.0 | 45.0 | 328.0 | 321.0 | 296.0 | 204.0 | 190.0 | 165.0 |
| 70% | 32.0 | 33.0 | 26.0 | 204.0 | 199.0 | 174.0 | 121.0 | 108.0 | 92.0 |
| 80% | 17.0 | 15.0 | 12.0 | 110.0 | 103.0 | 93.0 | 60.0 | 51.0 | 45.0 |
| 85% | 10.0 | 8.0 | 7.0 | 80.0 | 70.0 | 57.0 | 42.0 | 30.0 | 27.0 |
| 90% | 4.0 | 3.0 | 3.0 | 46.0 | 40.0 | 28.0 | 27.0 | 15.0 | 13.0 |
| 95% | 0.0 | 0.0 | 0.0 | 21.0 | 8.0 | 4.0 | 13.0 | 1.0 | 1.0 |
| 98% | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 |
| 99.5% | 0.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 |
| 99.8% | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 |
| 99.9% | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 |

Table 6.25 Flow Frequency Metrics for Control Points NEDI, NERO and VIKO

| | NEDI (CFS) | | | NERO (CFS) | | | VIKO (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 1,827 | 1,822 | 1,822 | 2,560 | 2,554 | 2,554 | 848.3 | 847.4 | 847.4 |
| Std Dev | 2,928 | 2,949 | 2,719 | 3,973 | 4,362 | 3,893 | 2,035 | 1,737 | 1,627 |
| Min | 1.0 | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 15.9 | 1.0 | 0.0 |
| Max | 49,900 | 53,444 | 30,203 | 49,700 | 81,250 | 46,166 | 62,200 | 70,122 | 32,616 |
| 0.1% | 32,794 | 32,407 | 26,612 | 37,298 | 47,211 | 36,569 | 30,422 | 16,538 | 17,052 |
| 0.2% | 24,922 | 21,797 | 23,655 | 32,231 | 38,947 | 30,774 | 16,528 | 11,243 | 14,202 |
| 0.5% | 18,756 | 16,704 | 15,270 | 25,564 | 24,993 | 23,040 | 10,100 | 7,737 | 8,829 |
| 1% | 12,600 | 13,832 | 12,725 | 18,084 | 19,629 | 18,227 | 7,011 | 5,746 | 7,048 |
| 2% | 9,780 | 10,449 | 9,518 | 13,600 | 15,193 | 14,454 | 4,917 | 4,838 | 5,539 |
| 5% | 6,720 | 6,839 | 6,928 | 9,960 | 10,027 | 9,706 | 3,234 | 3,345 | 3,758 |
| 10% | 4,680 | 4,902 | 4,929 | 6,970 | 6,782 | 6,787 | 2,050 | 2,214 | 2,333 |
| 15% | 3,730 | 3,623 | 3,880 | 5,302 | 5,111 | 5,215 | 1,472 | 1,613 | 1,601 |
| 20% | 2,870 | 2,830 | 2,966 | 4,170 | 3,927 | 4,159 | 1,100 | 1,212 | 1,194 |
| 30% | 1,940 | 1,869 | 1,920 | 2,690 | 2,462 | 2,586 | 686.0 | 787.0 | 709.0 |
| 40% | 1,250 | 1,175 | 1,200 | 1,640 | 1,494 | 1,667 | 434.0 | 522.0 | 440.0 |
| 50% | 748.0 | 727.0 | 760.0 | 1,020 | 943.0 | 1,059 | 300.0 | 325.0 | 275.0 |
| 60% | 450.0 | 439.0 | 474.0 | 580.0 | 596.0 | 680.0 | 218.0 | 216.0 | 167.0 |
| 70% | 270.0 | 266.0 | 273.0 | 349.0 | 354.0 | 379.0 | 156.0 | 140.0 | 97.0 |
| 80% | 148.0 | 140.0 | 148.0 | 192.0 | 172.0 | 201.0 | 117.0 | 84.0 | 45.0 |
| 85% | 113.0 | 97.0 | 102.0 | 142.0 | 123.0 | 131.0 | 97.0 | 62.0 | 26.0 |
| 90% | 70.0 | 53.0 | 56.0 | 88.0 | 80.0 | 75.0 | 80.0 | 40.0 | 13.0 |
| 95% | 30.0 | 12.0 | 9.0 | 39.0 | 20.0 | 24.0 | 55.0 | 20.0 | 2.0 |
| 98% | 7.0 | 0.0 | 0.0 | 10.0 | 1.0 | 0.0 | 40.0 | 7.0 | 0.0 |
| 99% | 3.0 | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 | 32.0 | 4.0 | 0.0 |
| 99.5% | 2.0 | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | 25.0 | 2.0 | 0.0 |
| 99.8% | 1.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 22.0 | 2.0 | 0.0 |
| 99.9% | 1.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 20.0 | 1.0 | 0.0 |

Table 6.26 Flow Frequency Metrics for Control Point NEEV

| | NEEV (CFS) | | |
|---|---|---|---|
| | USGS | MDNF | DDNF |
| Mean | 6,593 | 6,564 | 6,564 |
| Std Dev | 9,001 | 9,150 | 8,833 |
| Min | 62.9 | 21.4 | 0.0 |
| Max | 92,100 | 103,114 | 103,261 |
| 0.1% | 77,520 | 77,362 | 75,502 |
| 0.2% | 65,394 | 67,497 | 63,482 |
| 0.5% | 52,000 | 55,482 | 49,836 |
| 1% | 44,000 | 42,533 | 41,995 |
| 2% | 32,600 | 33,772 | 33,878 |
| 5% | 23,800 | 23,458 | 23,243 |
| 10% | 17,600 | 17,199 | 17,139 |
| 15% | 13,600 | 13,338 | 13,456 |
| 20% | 10,900 | 10,802 | 10,603 |
| 30% | 7,394 | 7,091 | 7,172 |
| 40% | 4,600 | 4,766 | 4,773 |
| 50% | 2,840 | 3,053 | 3,127 |
| 60% | 1,880 | 1,910 | 2,118 |
| 70% | 1,330 | 1,212 | 1,292 |
| 80% | 819.0 | 717.0 | 765.0 |
| 85% | 602.0 | 528.0 | 573.0 |
| 90% | 443.0 | 373.0 | 375.0 |
| 95% | 267.0 | 182.0 | 205.0 |
| 98% | 165.0 | 94.0 | 72.0 |
| 99% | 123.0 | 63.0 | 17.0 |
| 99.5% | 93.0 | 51.0 | 0.0 |
| 99.8% | 81.0 | 39.0 | 0.0 |
| 99.9% | 74.0 | 24.0 | 0.0 |

Table 6.27 summarizes the comparative scores, made through the qualitative comparison of both flow frequency metrics at a control.

Table 6.27 Comparative Evaluation of Flow Frequency Metrics for the Neches WAM

| CP | Data Period | Comparative Score USGS vs. MDNF | Comparative Score USGS vs. DDNF |
|---|---|---|---|
| Total | | 7 | 7 |
| MUJA | 01/01/1940-12/31/1960 | 1 | 1 |
| ANLU | 01/01/1940-12/31/1960 | 1 | 1 |
| NENE | 01/01/1940-12/31/1960 | 1 | 1 |
| NEDI | 01/01/1940-12/31/1960 | 1 | 1 |
| NERO | 01/01/1940-12/31/1960 | 1 | 1 |
| VIKO | 01/01/1940-12/31/1960 | 1 | 1 |
| NEEV | 01/01/1940-12/31/1960 | 1 | 1 |

The DHRAM method quantitatively evaluates how much the hydrologic characteristics of MDNF and DDNF are similar to or different from USGS daily recorded flows at the seven control points. Table 6.28 summarizes the scores of MDNF and DDNF based on the USGS daily recorded flows at seven control points.

Table 6.28 indicates that both MDNF and DDNF have similar hydrological characteristics to USGS daily recorded flows at seven control points. MDNFs at the two control points, MUJA and VIKO are more identical to USGS daily recorded flows than DDNFs, while DDNF at NERO is more similar to USGS daily recorded flows than MDNF. Both MDNF and DDNF at the other four control points have the same impact points. The detailed evaluation sheets for the seven control points are tabulated in Tables 6.29 to 6.35.

Table 6.28 Impact Points by the DHRAM Method for the Neches WAM

| CP | Data Period | Impact Points | |
|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF |
| Total | | 20 | 22 |
| MUJA | 01/01/1940-12/31/1960 | 5 | 6 |
| ANLU | 01/01/1940-12/31/1960 | 4 | 4 |
| NENE | 01/01/1940-12/31/1960 | 3 | 3 |
| NEDI | 01/01/1940-12/31/1960 | 1 | 1 |
| NERO | 01/01/1940-12/31/1960 | 3 | 0 |
| VIKO | 01/01/1940-12/31/1960 | 3 | 7 |
| NEEV | 01/01/1940-12/31/1960 | 1 | 1 |

Table 6.29 indicates that the amount of daily maximum and minimum flows of NDMF and DDMF are nearly to the same as the USGS daily recorded flows according to the results of parameter group #2, but the flow timings of both MDNF and DDNF are slightly different from the USGS daily recorded flows according to the results of parameter group #3 and #4 at MUJA.

Table 6.29 Evaluation Sheet by DHRAM Method for Control Point MUJA

| Control Point: | MUJA | Period: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 394.4 | 0.8771 | 404.1 | 0.851 | | 2.5% | 3.0% | 404.1 | 0.851 | | 2.5% | 3.0% |
| February | 463.2 | 0.6879 | 482.1 | 0.6637 | | 4.1% | 3.5% | 482.1 | 0.6636 | | 4.1% | 3.5% |
| March | 440.2 | 0.7642 | 454.4 | 0.7327 | | 3.2% | 4.1% | 454.4 | 0.7327 | | 3.2% | 4.1% |
| April | 440.6 | 0.7924 | 454.6 | 0.7963 | | 3.2% | 0.5% | 454.6 | 0.7963 | | 3.2% | 0.5% |
| May | 648.1 | 0.9665 | 654.5 | 0.9526 | | 1.0% | 1.4% | 654.4 | 0.9526 | | 1.0% | 1.4% |
| June | 230.5 | 1.092 | 233.7 | 1.083 | | 1.4% | 0.8% | 233.8 | 1.083 | | 1.4% | 0.8% |
| July | 91.13 | 2.255 | 93.33 | 2.199 | | 2.4% | 2.5% | 93.33 | 2.199 | | 2.4% | 2.5% |
| August | 32.16 | 1.501 | 40.2 | 1.334 | | 25.0% | 11.1% | 40.19 | 1.334 | | 25.0% | 11.1% |
| September | 42.99 | 1.168 | 41.05 | 1.018 | | 4.5% | 12.8% | 41.04 | 1.018 | | 4.5% | 12.8% |
| October | 99.92 | 1.885 | 103.9 | 1.831 | | 4.0% | 2.9% | 103.9 | 1.831 | | 4.0% | 2.9% |
| November | 293.5 | 1.691 | 299.7 | 1.646 | | 2.1% | 2.7% | 299.7 | 1.646 | | 2.1% | 2.7% |
| December | 354.4 | 1.125 | 363.2 | 1.092 | | 2.5% | 2.9% | 363.2 | 1.092 | | 2.5% | 2.9% |
| | | | | | Average | 4.7% | 4.0% | | | Average | 4.7% | 4.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 3.952 | 1.476 | 2.286 | 1.439 | | 42.2% | 2.5% | 1.667 | 2.073 | | 57.8% | 40.4% |
| 3-day minimum | 4.159 | 1.417 | 2.73 | 1.494 | | 34.4% | 5.4% | 2.222 | 1.802 | | 46.6% | 27.2% |
| 7-day minimum | 4.81 | 1.294 | 4.109 | 1.446 | | 14.6% | 11.7% | 3.19 | 1.63 | | 33.7% | 26.0% |
| 30-day minimum | 9.541 | 0.9749 | 13.84 | 1.262 | | 45.1% | 29.4% | 14.46 | 1.364 | | 51.6% | 39.9% |
| 90-day minimum | 37.97 | 1.492 | 40.76 | 1.332 | | 7.3% | 10.7% | 39.92 | 1.246 | | 5.1% | 16.5% |
| 1-day maximum | 5809 | 0.7462 | 6461 | 1.018 | | 11.2% | 36.4% | 4000 | 0.7645 | | 31.1% | 2.5% |
| 3-day maximum | 4776 | 0.7086 | 3611 | 0.7374 | | 24.4% | 4.1% | 3354 | 0.6369 | | 29.8% | 10.1% |
| 7-day maximum | 3122 | 0.6227 | 2450 | 0.6204 | | 21.5% | 0.4% | 2787 | 0.6007 | | 10.7% | 3.5% |
| 30-day maximum | 1205 | 0.5283 | 1175 | 0.4958 | | 2.5% | 6.2% | 1234 | 0.4777 | | 2.4% | 9.6% |
| 90-day maximum | 682.1 | 0.4605 | 679.7 | 0.4319 | | 0.4% | 6.2% | 692.6 | 0.4372 | | 1.5% | 5.1% |
| | | | | | Average | 20.3% | 11.3% | | | Average | 27.0% | 18.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 228.9 | 0.06412 | 225.9 | 0.2181 | | 1.3% | 240.1% | 201.7 | 0.2397 | | 11.9% | 273.8% |
| Date of maximum | 151.3 | 0.2532 | 151.6 | 0.262 | | 0.2% | 3.5% | 78 | 0.1588 | | 48.4% | 37.3% |
| | | | | | Average | 0.8% | 121.8% | | | Average | 30.2% | 155.6% |
| | | | | | Score | 0 | 3 | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4.048 | 0.5551 | 6.333 | 0.4531 | | 56.4% | 18.4% | 6.905 | 0.4195 | | 70.6% | 24.4% |
| Low pulse duration | 32.47 | 1.109 | 16.23 | 0.7937 | | 50.0% | 28.4% | 13.72 | 0.7882 | | 57.7% | 28.9% |
| High pulse count | 4.095 | 0.7984 | 5.714 | 0.5369 | | 39.5% | 32.8% | 4.667 | 0.5881 | | 14.0% | 26.3% |
| High pulse duration | 4.812 | 0.3246 | 4.96 | 0.6773 | | 3.1% | 108.7% | 6.665 | 0.3676 | | 38.5% | 13.2% |
| | | | | | Average | 37.3% | 47.1% | | | Average | 45.2% | 23.2% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 146 | 0.6284 | 251.9 | 0.5009 | | 72.5% | 20.3% | 133.6 | 0.4131 | | 8.5% | 34.3% |
| Fall rate | -71.76 | -0.5708 | -68.2 | -0.5388 | | 5.0% | 5.6% | -53.79 | -0.466 | | 25.0% | 18.4% |
| Number of reversals | 70.95 | 0.1747 | 80.86 | 0.2305 | | 14.0% | 31.9% | 61.48 | 0.1874 | | 13.3% | 7.3% |
| | | | | | Average | 30.5% | 19.3% | | | Average | 15.6% | 20.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | MDNF | | | DDNF |
|---|---|---|---|---|
| Total Point | 5 | | Total Point | 6 |
| Classification | 3 | | Classification | 3 |
| note: | Moderate risk of impact | | note: | Moderate risk of impact |

Table 6.30 also describes that the amount of daily maximum and minimum flows of NDMF and DDMF are similar to the USGS daily recorded flows according to the results of parameter group #2, but the flow timings of both MDNF and DDNF are slightly different from the USGS daily recorded flows according to the results of parameter group #3 at ANLU.

Table 6.30 Evaluation Sheet by DHRAM Method for Control Point ANLU

| Control Point: | ANLU | Period: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 1881 | 0.9506 | 1892 | 0.9449 | | 0.6% | 0.6% | 1892 | 0.9449 | | 0.6% | 0.6% |
| February | 2123 | 0.6507 | 2140 | 0.6469 | | 0.8% | 0.6% | 2140 | 0.6469 | | 0.8% | 0.6% |
| March | 2055 | 0.6846 | 2065 | 0.6796 | | 0.5% | 0.7% | 2065 | 0.6796 | | 0.5% | 0.7% |
| April | 1819 | 0.6739 | 1830 | 0.6703 | | 0.6% | 0.5% | 1830 | 0.6703 | | 0.6% | 0.5% |
| May | 2777 | 0.963 | 2785 | 0.9611 | | 0.3% | 0.2% | 2785 | 0.9611 | | 0.3% | 0.2% |
| June | 1065 | 0.9056 | 1076 | 0.9185 | | 1.0% | 1.4% | 1076 | 0.9185 | | 1.0% | 1.4% |
| July | 423.8 | 1.32 | 424.8 | 1.313 | | 0.2% | 0.5% | 424.8 | 1.313 | | 0.2% | 0.5% |
| August | 143.8 | 0.7119 | 148.5 | 0.7294 | | 3.3% | 2.5% | 148.5 | 0.7295 | | 3.3% | 2.5% |
| September | 269.1 | 1.482 | 266.4 | 1.446 | | 1.0% | 2.4% | 266.4 | 1.446 | | 1.0% | 2.4% |
| October | 505.5 | 1.539 | 504.1 | 1.545 | | 0.3% | 0.4% | 504.1 | 1.545 | | 0.3% | 0.4% |
| November | 1091 | 1.533 | 1092 | 1.528 | | 0.1% | 0.3% | 1092 | 1.528 | | 0.1% | 0.3% |
| December | 1457 | 1.182 | 1459 | 1.178 | | 0.1% | 0.3% | 1459 | 1.178 | | 0.1% | 0.3% |
| | | | | | Average | 0.7% | 0.9% | | | Average | 0.7% | 0.9% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 45.33 | 0.7467 | 24.33 | 1.107 | | 46.3% | 48.3% | 17.52 | 1.678 | | 61.4% | 124.7% |
| 3-day minimum | 47.06 | 0.7605 | 26.73 | 1.073 | | 43.2% | 41.1% | 19.51 | 1.565 | | 58.5% | 105.8% |
| 7-day minimum | 50.86 | 0.7978 | 31.64 | 1.046 | | 37.8% | 31.1% | 22.95 | 1.378 | | 54.9% | 72.7% |
| 30-day minimum | 71.8 | 0.7753 | 61.34 | 0.8031 | | 14.6% | 3.6% | 51.55 | 0.872 | | 28.2% | 12.5% |
| 90-day minimum | 187.9 | 1.067 | 183.5 | 1.006 | | 2.3% | 5.7% | 185.5 | 1.027 | | 1.3% | 3.7% |
| 1-day maximum | 11530 | 0.7044 | 11310 | 0.6779 | | 1.9% | 3.8% | 9960 | 0.599 | | 13.6% | 15.0% |
| 3-day maximum | 10940 | 0.7021 | 9974 | 0.6811 | | 8.8% | 3.0% | 9514 | 0.6152 | | 13.0% | 12.4% |
| 7-day maximum | 9309 | 0.6811 | 8403 | 0.6152 | | 9.7% | 9.7% | 8772 | 0.6089 | | 5.8% | 10.6% |
| 30-day maximum | 4717 | 0.5809 | 4689 | 0.56 | | 0.6% | 3.6% | 4850 | 0.5715 | | 2.8% | 1.6% |
| 90-day maximum | 2860 | 0.5014 | 2879 | 0.5068 | | 0.7% | 1.1% | 2896 | 0.5068 | | 1.3% | 1.1% |
| | | | | | Average | 16.6% | 15.1% | | | Average | 24.1% | 36.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 259.1 | 0.05849 | 234.5 | 0.2033 | | 9.5% | 247.6% | 214.9 | 0.2492 | | 17.1% | 326.1% |
| Date of maximum | 133 | 0.2495 | 112 | 0.241 | | 15.8% | 3.4% | 115.1 | 0.2397 | | 13.5% | 3.9% |
| | | | | | Average | 12.6% | 125.5% | | | Average | 15.3% | 165.0% |
| | | | | | Score | 1 | 3 | | | Score | 1 | 3 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.238 | 0.4132 | 3.857 | 0.436 | | 19.1% | 5.5% | 4.476 | 0.3645 | | 38.2% | 11.8% |
| Low pulse duration | 32.89 | 0.8949 | 28.48 | 0.9479 | | 13.4% | 5.9% | 21.47 | 0.7491 | | 34.7% | 16.3% |
| High pulse count | 3.476 | 0.9697 | 3.81 | 0.7636 | | 9.6% | 21.3% | 3.143 | 0.6919 | | 9.6% | 28.6% |
| High pulse duration | 9.922 | 0.5863 | 9.019 | 0.6294 | | 9.1% | 7.4% | 11.96 | 0.6221 | | 20.5% | 6.1% |
| | | | | | Average | 12.8% | 10.0% | | | Average | 25.8% | 15.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 248.1 | 0.6388 | 357.1 | 0.5568 | | 43.9% | 12.8% | 265.4 | 0.5136 | | 7.0% | 19.6% |
| Fall rate | -144.9 | -0.5704 | -134.2 | -0.4996 | | 7.4% | 12.4% | -136.4 | -0.4913 | | 5.9% | 13.9% |
| Number of reversals | 59.43 | 0.1839 | 62.43 | 0.2468 | | 5.0% | 34.2% | 48.33 | 0.1909 | | 18.7% | 3.8% |
| | | | | | Average | 18.8% | 19.8% | | | Average | 10.5% | 12.4% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Total Point | | 4 | Total Point | 4 |
| Classification | | 2 | Classification | 2 |
| note: | Low risk of impact | | note: Low risk of impact | |

Table 6.31also shows that the amount of daily maximum and minimum flows of NDMF and DDMF are similar to the USGS daily recorded flows according to the results of parameter group #2, but the flow timings of both MDNF and DDNF are much more variable, compared to the USGS daily recorded flows according to the absolute changes of coefficient of variance (CV) on parameter group #3 at NENE.

Table 6.31 Evaluation Sheet by DHRAM Method for Control Point NENE

| Control Point: | NENE | Period: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 1051 | 0.7852 | 1048 | 0.7887 | | 0.3% | 0.4% | 1048 | 0.7886 | | 0.3% | 0.4% |
| February | 1162 | 0.7472 | 1159 | 0.7506 | | 0.3% | 0.5% | 1159 | 0.7506 | | 0.3% | 0.5% |
| March | 1280 | 0.7531 | 1277 | 0.7559 | | 0.2% | 0.4% | 1277 | 0.7559 | | 0.2% | 0.4% |
| April | 1517 | 1.068 | 1514 | 1.071 | | 0.2% | 0.3% | 1514 | 1.071 | | 0.2% | 0.3% |
| May | 1738 | 0.8391 | 1735 | 0.8402 | | 0.2% | 0.1% | 1735 | 0.8402 | | 0.2% | 0.1% |
| June | 800.6 | 1.081 | 796.9 | 1.087 | | 0.5% | 0.6% | 796.8 | 1.087 | | 0.5% | 0.6% |
| July | 241.4 | 1.205 | 236.9 | 1.233 | | 1.9% | 2.3% | 236.9 | 1.233 | | 1.9% | 2.3% |
| August | 73.95 | 1.293 | 68.85 | 1.395 | | 6.9% | 7.9% | 68.86 | 1.395 | | 6.9% | 7.9% |
| September | 121.4 | 1.68 | 117.8 | 1.738 | | 3.0% | 3.5% | 117.8 | 1.738 | | 3.0% | 3.5% |
| October | 234.6 | 1.164 | 230.7 | 1.187 | | 1.7% | 2.0% | 230.7 | 1.187 | | 1.7% | 2.0% |
| November | 591.3 | 1.529 | 588.1 | 1.538 | | 0.5% | 0.6% | 588 | 1.538 | | 0.6% | 0.6% |
| December | 813 | 1.044 | 810.1 | 1.047 | | 0.4% | 0.3% | 810.1 | 1.047 | | 0.4% | 0.3% |
| | | | | | Average | 1.3% | 1.6% | | | Average | 1.3% | 1.6% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 22.19 | 0.7294 | 11 | 1.59 | | 50.4% | 118.0% | 10.76 | 1.742 | | 51.5% | 138.8% |
| 3-day minimum | 23.3 | 0.7385 | 12.57 | 1.648 | | 46.1% | 123.2% | 12.46 | 1.874 | | 46.5% | 153.8% |
| 7-day minimum | 25.11 | 0.7448 | 16.4 | 1.698 | | 34.7% | 128.0% | 18.48 | 2.291 | | 26.4% | 207.6% |
| 30-day minimum | 36.6 | 0.7336 | 37.99 | 1.202 | | 3.8% | 63.8% | 38.56 | 1.453 | | 5.4% | 98.1% |
| 90-day minimum | 108.1 | 1.228 | 101.4 | 1.278 | | 6.2% | 4.1% | 100.2 | 1.26 | | 7.3% | 2.6% |
| 1-day maximum | 11160 | 0.8361 | 9742 | 0.7079 | | 12.7% | 15.3% | 8356 | 0.6535 | | 25.1% | 21.8% |
| 3-day maximum | 10220 | 0.8114 | 7131 | 0.5223 | | 30.2% | 35.6% | 7671 | 0.6652 | | 24.9% | 18.0% |
| 7-day maximum | 7940 | 0.7466 | 5925 | 0.5073 | | 25.4% | 32.1% | 6718 | 0.6076 | | 15.4% | 18.6% |
| 30-day maximum | 3323 | 0.5555 | 3246 | 0.5277 | | 2.3% | 5.0% | 3320 | 0.5299 | | 0.1% | 4.6% |
| 90-day maximum | 1869 | 0.5084 | 1839 | 0.5023 | | 1.6% | 1.2% | 1858 | 0.5048 | | 0.6% | 0.7% |
| | | | | | Average | 21.3% | 52.6% | | | Average | 20.3% | 66.5% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 246.7 | 0.05608 | 243 | 0.1924 | | 1.5% | 243.1% | 233.9 | 0.1937 | | 5.2% | 245.4% |
| Date of maximum | 136.1 | 0.2046 | 131.7 | 0.2063 | | 3.2% | 0.8% | 140.9 | 0.2411 | | 3.5% | 17.8% |
| | | | | | Average | 2.4% | 122.0% | | | Average | 4.4% | 131.6% |
| | | | | | Score | 0 | 3 | | | Score | 0 | 3 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.238 | 0.5066 | 4.095 | 0.5563 | | 26.5% | 9.8% | 4.238 | 0.5218 | | 30.9% | 3.0% |
| Low pulse duration | 39.03 | 1.044 | 29.04 | 1.083 | | 25.6% | 3.7% | 29.08 | 1.149 | | 25.5% | 10.1% |
| High pulse count | 3.238 | 0.7807 | 4.381 | 0.6394 | | 35.3% | 18.1% | 4.714 | 0.5658 | | 45.6% | 27.5% |
| High pulse duration | 7.654 | 0.3404 | 8.271 | 0.4766 | | 8.1% | 40.0% | 7.394 | 0.4883 | | 3.4% | 43.4% |
| | | | | | Average | 23.9% | 17.9% | | | Average | 26.3% | 21.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 206.1 | 0.7029 | 278.6 | 0.4889 | | 35.2% | 30.4% | 201.1 | 0.435 | | 2.4% | 38.1% |
| Fall rate | -113.3 | -0.5933 | -118 | -0.5907 | | 4.1% | 0.4% | -121.3 | -0.5217 | | 7.1% | 12.1% |
| Number of reversals | 55.76 | 0.1622 | 69.67 | 0.2605 | | 24.9% | 60.6% | 53.33 | 0.19 | | 4.4% | 17.1% |
| | | | | | Average | 21.4% | 30.5% | | | Average | 4.6% | 22.4% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Total Point | | 3 | Total Point | 3 |
| Classification | | 2 | Classification | 2 |
| note: | Low risk of impact | | note: Low risk of impact | |

The detailed evaluation sheets at control point NEDI and NEEV show that hydrologic characteristics of both NDMF and DDMF are almost identical to the USGS daily recorded flows as tabulated in Tables 6.32 and 6.33, respectively.

Table 6.32 Evaluation Sheet by DHRAM Method for Control Point NEDI

| Control Point: | NEDI | Period: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 2513 | 0.9603 | 2506 | 0.9637 | | 0.3% | 0.4% | 2506 | 0.9637 | | 0.3% | 0.4% |
| February | 2839 | 0.7398 | 2820 | 0.7462 | | 0.7% | 0.9% | 2821 | 0.7461 | | 0.6% | 0.9% |
| March | 2877 | 0.7336 | 2870 | 0.7366 | | 0.2% | 0.4% | 2870 | 0.7367 | | 0.2% | 0.4% |
| April | 2786 | 0.9575 | 2839 | 0.946 | | 1.9% | 1.2% | 2839 | 0.946 | | 1.9% | 1.2% |
| May | 4118 | 0.9686 | 4084 | 0.9543 | | 0.8% | 1.5% | 4084 | 0.9543 | | 0.8% | 1.5% |
| June | 1928 | 0.794 | 1903 | 0.7972 | | 1.3% | 0.4% | 1903 | 0.7972 | | 1.3% | 0.4% |
| July | 660.9 | 1.076 | 660.6 | 1.121 | | 0.0% | 4.2% | 660.6 | 1.121 | | 0.0% | 4.2% |
| August | 198.2 | 0.9611 | 188.5 | 0.9085 | | 4.9% | 5.5% | 188.5 | 0.9085 | | 4.9% | 5.5% |
| September | 300.8 | 1.485 | 285.4 | 1.479 | | 5.1% | 0.4% | 285.4 | 1.479 | | 5.1% | 0.4% |
| October | 496.5 | 1.41 | 515.2 | 1.365 | | 3.8% | 3.2% | 515.2 | 1.365 | | 3.8% | 3.2% |
| November | 1344 | 1.421 | 1339 | 1.432 | | 0.4% | 0.8% | 1339 | 1.432 | | 0.4% | 0.8% |
| December | 1921 | 1.232 | 1908 | 1.243 | | 0.7% | 0.9% | 1908 | 1.243 | | 0.7% | 0.9% |
| | | | | | Average | 1.7% | 1.6% | | | Average | 1.7% | 1.6% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 67.1 | 0.7394 | 41.48 | 1.306 | | 38.2% | 76.6% | 38.57 | 1.383 | | 42.5% | 87.0% |
| 3-day minimum | 69.08 | 0.7369 | 43.35 | 1.287 | | 37.2% | 74.7% | 40.37 | 1.345 | | 41.6% | 82.5% |
| 7-day minimum | 71.7 | 0.7351 | 47.2 | 1.238 | | 34.2% | 68.4% | 45.59 | 1.277 | | 36.4% | 73.7% |
| 30-day minimum | 94.55 | 0.7492 | 87.65 | 0.9052 | | 7.3% | 20.8% | 88.23 | 0.9952 | | 6.7% | 32.8% |
| 90-day minimum | 228.1 | 1.031 | 212.3 | 1.042 | | 6.9% | 1.1% | 219.6 | 1.056 | | 3.7% | 2.4% |
| 1-day maximum | 15130 | 0.8048 | 18870 | 0.7151 | | 24.7% | 11.1% | 11240 | 0.7156 | | 25.7% | 11.1% |
| 3-day maximum | 14060 | 0.8107 | 13190 | 0.7169 | | 6.2% | 11.6% | 10720 | 0.6962 | | 23.8% | 14.1% |
| 7-day maximum | 11790 | 0.7757 | 10910 | 0.7071 | | 7.5% | 8.8% | 10030 | 0.7004 | | 14.9% | 9.7% |
| 30-day maximum | 6697 | 0.6446 | 6624 | 0.6264 | | 1.1% | 2.8% | 6725 | 0.6252 | | 0.4% | 3.0% |
| 90-day maximum | 4086 | 0.5638 | 4013 | 0.5515 | | 1.8% | 2.2% | 4035 | 0.5554 | | 1.2% | 1.5% |
| | | | | | Average | 16.5% | 27.8% | | | Average | 19.7% | 31.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 259 | 0.1678 | 246 | 0.1837 | | 5.0% | 9.5% | 250.6 | 0.1007 | | 3.2% | 40.0% |
| Date of maximum | 133.3 | 0.2524 | 132 | 0.2405 | | 1.0% | 4.7% | 131.2 | 0.2468 | | 1.6% | 2.2% |
| | | | | | Average | 3.0% | 7.1% | | | Average | 2.4% | 21.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 2.571 | 0.4183 | 3.476 | 0.6008 | | 35.2% | 43.6% | 2.476 | 0.6589 | | 3.7% | 57.5% |
| Low pulse duration | 39.72 | 0.7896 | 33.7 | 0.8477 | | 15.2% | 7.4% | 50.98 | 0.9824 | | 28.3% | 24.4% |
| High pulse count | 3.333 | 0.7727 | 5.143 | 0.7257 | | 54.3% | 6.1% | 2.476 | 0.8626 | | 25.7% | 11.6% |
| High pulse duration | 10.31 | 0.7513 | 6.856 | 0.6899 | | 33.5% | 8.2% | 17.42 | 0.4724 | | 69.0% | 37.1% |
| | | | | | Average | 34.5% | 16.3% | | | Average | 31.7% | 32.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 337 | 0.7019 | 670.7 | 0.7211 | | 99.0% | 2.7% | 257.7 | 0.6032 | | 23.5% | 14.1% |
| Fall rate | -185.2 | -0.6598 | -248.2 | -0.6586 | | 34.0% | 0.2% | -125.7 | -0.604 | | 32.1% | 8.5% |
| Number of reversals | 55.76 | 0.1559 | 70.86 | 0.194 | | 27.1% | 24.4% | 44.19 | 0.2131 | | 20.7% | 36.7% |
| | | | | | Average | 53.4% | 9.1% | | | Average | 25.5% | 19.7% |
| | | | | | Score | 1 | 0 | | | Score | 0 | 0 |
| | | | | | Total Point | 1 | | | | Total Point | 1 | |
| | | | | | Classification | 2 | | | | Classification | 2 | |
| | | | | | note: | Low risk of impact | | | | note: | Low risk of impact | |

# Table 6.33 Evaluation Sheet by DHRAM Method for Control Point NEEV

Control Point: NEEV    Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 9627 | 0.9046 | 9646 | 0.9 | | 0.2% | 0.5% | 9646 | 0.9 | | 0.2% | 0.5% |
| February | 10970 | 0.6999 | 11010 | 0.6911 | | 0.4% | 1.3% | 11010 | 0.6911 | | 0.4% | 1.3% |
| March | 10020 | 0.6157 | 10090 | 0.6068 | | 0.7% | 1.4% | 10090 | 0.6068 | | 0.7% | 1.4% |
| April | 9612 | 0.7028 | 9769 | 0.6835 | | 1.6% | 2.7% | 9769 | 0.6835 | | 1.6% | 2.7% |
| May | 13160 | 1.009 | 13110 | 1.011 | | 0.4% | 0.2% | 13110 | 1.011 | | 0.4% | 0.2% |
| June | 7301 | 0.8838 | 7128 | 0.9049 | | 2.4% | 2.4% | 7128 | 0.9049 | | 2.4% | 2.4% |
| July | 2540 | 0.6723 | 2395 | 0.7914 | | 5.7% | 17.7% | 2395 | 0.7914 | | 5.7% | 17.7% |
| August | 1407 | 0.7147 | 1178 | 0.8039 | | 16.3% | 12.5% | 1178 | 0.8039 | | 16.3% | 12.5% |
| September | 1241 | 0.9425 | 1241 | 1.156 | | 0.0% | 22.7% | 1241 | 1.156 | | 0.0% | 22.7% |
| October | 1903 | 1.252 | 1917 | 1.222 | | 0.7% | 2.4% | 1917 | 1.222 | | 0.7% | 2.4% |
| November | 4109 | 1.479 | 4533 | 1.433 | | 10.3% | 3.1% | 4533 | 1.433 | | 10.3% | 3.1% |
| December | 7484 | 1.367 | 7034 | 1.233 | | 6.0% | 9.8% | 7034 | 1.233 | | 6.0% | 9.8% |
| | | | | | Average | 3.7% | 6.4% | | | Average | 3.7% | 6.4% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 388 | 0.7217 | 219.8 | 0.7456 | | 43.4% | 3.3% | 261.9 | 0.8542 | | 32.5% | 18.4% |
| 3-day minimum | 400.1 | 0.7354 | 230.4 | 0.746 | | 42.4% | 1.4% | 273.9 | 0.858 | | 31.5% | 16.7% |
| 7-day minimum | 420.2 | 0.7206 | 268.2 | 0.7042 | | 36.2% | 2.3% | 296.7 | 0.8291 | | 29.4% | 15.1% |
| 30-day minimum | 536.7 | 0.6952 | 440.4 | 0.6928 | | 17.9% | 0.3% | 495.4 | 0.8076 | | 7.7% | 16.2% |
| 90-day minimum | 1013 | 0.7766 | 917.5 | 0.7594 | | 9.4% | 2.2% | 942.6 | 0.7485 | | 6.9% | 3.6% |
| 1-day maximum | 36590 | 0.625 | 40890 | 0.6397 | | 11.8% | 2.4% | 35780 | 0.6911 | | 2.2% | 10.6% |
| 3-day maximum | 36010 | 0.6225 | 38490 | 0.6531 | | 6.9% | 4.9% | 34490 | 0.6494 | | 4.2% | 4.3% |
| 7-day maximum | 33960 | 0.6223 | 35080 | 0.6535 | | 3.3% | 5.0% | 32350 | 0.6269 | | 4.7% | 0.7% |
| 30-day maximum | 22600 | 0.6282 | 22270 | 0.6118 | | 1.5% | 2.6% | 22370 | 0.6327 | | 1.0% | 0.7% |
| 90-day maximum | 14270 | 0.5346 | 14210 | 0.5287 | | 0.4% | 1.1% | 14200 | 0.5282 | | 0.5% | 1.2% |
| | | | | | Average | 17.3% | 2.6% | | | Average | 12.1% | 8.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 284.6 | 0.1009 | 282.7 | 0.09833 | | 0.7% | 2.5% | 257.5 | 0.1786 | | 9.5% | 77.0% |
| Date of maximum | 129.1 | 0.2685 | 143.6 | 0.2537 | | 11.2% | 5.5% | 134 | 0.2577 | | 3.8% | 4.0% |
| | | | | | Average | 5.9% | 4.0% | | | Average | 6.7% | 40.5% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.333 | 0.496 | 3.429 | 0.4754 | | 2.9% | 4.2% | 2.714 | 0.4381 | | 18.6% | 11.7% |
| Low pulse duration | 31.65 | 0.8456 | 36.19 | 1.383 | | 14.3% | 63.6% | 37.8 | 0.8698 | | 19.4% | 2.9% |
| High pulse count | 2.619 | 0.6666 | 3.524 | 0.9223 | | 34.6% | 38.4% | 2.905 | 0.8355 | | 10.9% | 25.3% |
| High pulse duration | 16.92 | 0.7145 | 12.94 | 0.4682 | | 23.5% | 34.5% | 16.27 | 0.6484 | | 3.8% | 9.3% |
| | | | | | Average | 18.8% | 35.1% | | | Average | 13.2% | 12.3% |
| | | | | | Score | 0 | 1 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 716.5 | 0.4394 | 1155 | 0.5363 | | 61.2% | 22.1% | 635.9 | 0.5119 | | 11.2% | 16.5% |
| Fall rate | -495.9 | -0.4231 | -502.6 | -0.5432 | | 1.4% | 28.4% | -375.2 | -0.5398 | | 24.3% | 27.6% |
| Number of reversals | 59.43 | 0.1984 | 69.57 | 0.2174 | | 17.1% | 9.6% | 44.67 | 0.1563 | | 24.8% | 21.2% |
| | | | | | Average | 26.5% | 20.0% | | | Average | 20.1% | 21.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| | MDNF | | DDNF | |
|---|---|---|---|---|
| Total Point | | 1 | | 1 |
| Classification | | 2 | | 2 |
| note: | Low risk of impact | | Low risk of impact | |

The DHRAH method evaluates 3 impact points for MDNF and 7 impact points for DDNF, respectively in comparison with the USGS daily recorded flows at control point VIKO as tabulated in Table 6.34. The minimum flows of DDNF are obviously different from the USGS daily recorded flows. The flow timings of both MDNF and DDNF are relatively variable and slightly different from the USGS daily recorded flows according to the absolute changes of coefficient of variance (CV) on parameter group #3.

Table 6.34 Evaluation Sheet by DHRAM Method for Control Point VIKO

Control Point: VIKO Period: 1940-1960

| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 1352 | 0.9072 | 1351 | 0.9072 | | 0.1% | 0.0% | 1351 | 0.9072 | | 0.1% | 0.0% |
| February | 1328 | 0.6261 | 1327 | 0.6261 | | 0.1% | 0.0% | 1327 | 0.6261 | | 0.1% | 0.0% |
| March | 1063 | 0.6857 | 1061 | 0.6857 | | 0.2% | 0.0% | 1061 | 0.6857 | | 0.2% | 0.0% |
| April | 1081 | 0.7904 | 1080 | 0.7904 | | 0.1% | 0.0% | 1080 | 0.7904 | | 0.1% | 0.0% |
| May | 1257 | 1.215 | 1256 | 1.215 | | 0.1% | 0.0% | 1256 | 1.215 | | 0.1% | 0.0% |
| June | 829.2 | 1.78 | 828.3 | 1.78 | | 0.1% | 0.0% | 828.2 | 1.78 | | 0.1% | 0.0% |
| July | 424.7 | 0.8235 | 424.2 | 0.8237 | | 0.1% | 0.0% | 424.2 | 0.8236 | | 0.1% | 0.0% |
| August | 259.6 | 1.142 | 259.2 | 1.142 | | 0.2% | 0.0% | 259.3 | 1.142 | | 0.1% | 0.0% |
| September | 242 | 0.8419 | 241.7 | 0.8419 | | 0.1% | 0.0% | 241.7 | 0.8419 | | 0.1% | 0.0% |
| October | 411.7 | 2.135 | 411.2 | 2.135 | | 0.1% | 0.0% | 411.2 | 2.135 | | 0.1% | 0.0% |
| November | 937.9 | 1.718 | 936.8 | 1.718 | | 0.1% | 0.0% | 936.8 | 1.718 | | 0.1% | 0.0% |
| December | 1028 | 1.283 | 1026 | 1.283 | | 0.2% | 0.0% | 1026 | 1.283 | | 0.2% | 0.0% |
| | | | | | Average | 0.1% | 0.0% | | | Average | 0.1% | 0.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 76 | 0.4845 | 12.62 | 1.147 | | 83.4% | 136.7% | 1.714 | 1.61 | | 97.7% | 232.3% |
| 3-day minimum | 77.27 | 0.4885 | 13.76 | 1.137 | | 82.2% | 132.8% | 1.921 | 1.514 | | 97.5% | 209.9% |
| 7-day minimum | 80.18 | 0.5002 | 17.59 | 1.107 | | 78.1% | 121.3% | 2.524 | 1.357 | | 96.9% | 171.3% |
| 30-day minimum | 99.05 | 0.5334 | 56.71 | 0.797 | | 42.7% | 49.4% | 26.46 | 1.178 | | 73.3% | 120.8% |
| 90-day minimum | 166.9 | 0.63 | 158.2 | 0.663 | | 5.2% | 5.2% | 151.5 | 0.6725 | | 9.2% | 6.7% |
| 1-day maximum | 15610 | 1.088 | 13710 | 1.247 | | 12.2% | 14.6% | 8496 | 0.8027 | | 45.6% | 26.2% |
| 3-day maximum | 12380 | 1.011 | 8351 | 1.022 | | 32.5% | 1.1% | 7959 | 0.8346 | | 35.7% | 17.4% |
| 7-day maximum | 7794 | 0.8487 | 6148 | 0.8267 | | 21.1% | 2.6% | 6812 | 0.7595 | | 12.6% | 10.5% |
| 30-day maximum | 3282 | 0.7681 | 3218 | 0.7108 | | 2.0% | 7.5% | 3303 | 0.7079 | | 0.6% | 7.8% |
| 90-day maximum | 1807 | 0.5561 | 1801 | 0.5471 | | 0.3% | 1.6% | 1817 | 0.5443 | | 0.6% | 2.1% |
| | | | | | Average | 36.0% | 47.3% | | | Average | 47.0% | 80.5% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 265 | 0.08349 | 236.9 | 0.185 | | 10.6% | 121.6% | 198.7 | 0.2033 | | 25.0% | 143.5% |
| Date of maximum | 165.5 | 0.2899 | 158.6 | 0.3023 | | 4.2% | 4.3% | 136.2 | 0.2719 | | 17.7% | 6.2% |
| | | | | | Average | 7.4% | 62.9% | | | Average | 21.4% | 74.9% |
| | | | | | Score | 1 | 2 | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 5.571 | 0.6657 | 5.286 | 0.4361 | | 5.1% | 34.5% | 6.857 | 0.349 | | 23.1% | 47.6% |
| Low pulse duration | 16.85 | 0.7441 | 18.19 | 0.6214 | | 8.0% | 16.5% | 12.95 | 0.3337 | | 23.1% | 55.2% |
| High pulse count | 3.81 | 0.7171 | 4.714 | 0.704 | | 23.7% | 1.8% | 4.571 | 0.6868 | | 20.0% | 4.2% |
| High pulse duration | 5.163 | 0.3755 | 6.124 | 0.5774 | | 18.6% | 53.8% | 7.579 | 0.5566 | | 46.8% | 48.2% |
| | | | | | Average | 13.9% | 26.6% | | | Average | 28.2% | 38.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 342.8 | 0.7148 | 507 | 0.7826 | | 47.9% | 9.5% | 271.4 | 0.5199 | | 20.8% | 27.3% |
| Fall rate | -184 | -0.7447 | -137.6 | -0.7988 | | 25.2% | 7.3% | -130.4 | -0.5373 | | 29.1% | 27.9% |
| Number of reversals | 69.14 | 0.1001 | 67.62 | 0.224 | | 2.2% | 123.8% | 53.9 | 0.1677 | | 22.0% | 67.5% |
| | | | | | Average | 25.1% | 46.8% | | | Average | 24.0% | 40.9% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |

| MDNF | | DDNF | |
|---|---|---|---|
| Total Point | 3 | Total Point | 7 |
| Classification | 2 | Classification | 3 |
| note: | Low risk of impact | note: | Moderate risk of impact |

Hydrologic characteristics of both NDMF and DDMF are almost identical to the USGS daily recorded flows at control point NERO as tabulated in Table 6.35.

Table 6.35 Evaluation Sheet by DHRAM Method for Control Point NERO

| Control Point: | NERO | Period: | 1940-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 3660 | 0.9727 | 3647 | 0.9776 | | 0.4% | 0.5% | 3647 | 0.9776 | | 0.4% | 0.5% |
| February | 4131 | 0.8002 | 4127 | 0.8005 | | 0.1% | 0.0% | 4127 | 0.8005 | | 0.1% | 0.0% |
| March | 3872 | 0.6988 | 3864 | 0.7009 | | 0.2% | 0.3% | 3864 | 0.7009 | | 0.2% | 0.3% |
| April | 3899 | 0.9472 | 3964 | 0.9291 | | 1.7% | 1.9% | 3964 | 0.9291 | | 1.7% | 1.9% |
| May | 5695 | 1.043 | 5650 | 1.029 | | 0.8% | 1.3% | 5650 | 1.029 | | 0.8% | 1.3% |
| June | 2762 | 0.8409 | 2735 | 0.8476 | | 1.0% | 0.8% | 2735 | 0.8475 | | 1.0% | 0.8% |
| July | 849.2 | 0.9768 | 861.8 | 1.009 | | 1.5% | 3.3% | 861.7 | 1.009 | | 1.5% | 3.3% |
| August | 335.6 | 1.081 | 303.7 | 1.075 | | 9.5% | 0.6% | 303.7 | 1.074 | | 9.5% | 0.6% |
| September | 354.4 | 1.282 | 349.7 | 1.315 | | 1.3% | 2.6% | 349.7 | 1.315 | | 1.3% | 2.6% |
| October | 641 | 1.29 | 666 | 1.263 | | 3.9% | 2.1% | 666.1 | 1.263 | | 3.9% | 2.1% |
| November | 1905 | 1.553 | 1884 | 1.566 | | 1.1% | 0.8% | 1884 | 1.566 | | 1.1% | 0.8% |
| December | 2712 | 1.302 | 2694 | 1.313 | | 0.7% | 0.8% | 2694 | 1.313 | | 0.7% | 0.8% |
| | | | | | Average | 1.8% | 1.3% | | | Average | 1.8% | 1.3% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 85.52 | 0.7631 | 55.33 | 1.06 | | 35.3% | 38.9% | 59.52 | 0.987 | | 30.4% | 29.3% |
| 3-day minimum | 88 | 0.7714 | 56.86 | 1.049 | | 35.4% | 36.0% | 62.29 | 0.9962 | | 29.2% | 29.1% |
| 7-day minimum | 93.5 | 0.7813 | 60.83 | 1.022 | | 34.9% | 30.8% | 69.37 | 1.013 | | 25.8% | 29.7% |
| 30-day minimum | 125 | 0.78 | 106.7 | 0.9015 | | 14.6% | 15.6% | 118.5 | 0.934 | | 5.2% | 19.7% |
| 90-day minimum | 298.6 | 0.9893 | 272.7 | 0.9162 | | 8.7% | 7.4% | 291.5 | 0.9764 | | 2.4% | 1.3% |
| 1-day maximum | 18100 | 0.7032 | 29450 | 0.6672 | | 62.7% | 5.1% | 17060 | 0.636 | | 5.7% | 9.6% |
| 3-day maximum | 17550 | 0.7041 | 21560 | 0.711 | | 22.8% | 1.0% | 15990 | 0.6484 | | 8.9% | 7.9% |
| 7-day maximum | 15830 | 0.6945 | 16340 | 0.7104 | | 3.2% | 2.3% | 14700 | 0.6686 | | 7.1% | 3.7% |
| 30-day maximum | 9420 | 0.6629 | 9445 | 0.6452 | | 0.3% | 2.7% | 9497 | 0.6516 | | 0.8% | 1.7% |
| 90-day maximum | 5762 | 0.5623 | 5693 | 0.5583 | | 1.2% | 0.7% | 5710 | 0.5624 | | 0.9% | 0.0% |
| | | | | | Average | 21.9% | 14.0% | | | Average | 11.6% | 13.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 255.8 | 0.1731 | 248.6 | 0.1729 | | 2.8% | 0.1% | 251.3 | 0.1752 | | 1.8% | 1.2% |
| Date of maximum | 136.6 | 0.2463 | 151.2 | 0.2872 | | 10.7% | 16.6% | 134.7 | 0.258 | | 1.4% | 4.8% |
| | | | | | Average | 6.8% | 8.4% | | | Average | 1.6% | 3.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 2.762 | 0.5714 | 2.524 | 0.4271 | | 8.6% | 25.3% | 2.714 | 0.4681 | | 1.7% | 18.1% |
| Low pulse duration | 43.88 | 0.9441 | 41.85 | 0.8764 | | 4.6% | 7.2% | 43.51 | 1.078 | | 0.8% | 14.2% |
| High pulse count | 2.762 | 0.7842 | 6.381 | 0.6911 | | 131.0% | 11.9% | 3.619 | 0.8031 | | 31.0% | 2.4% |
| High pulse duration | 14.75 | 0.6411 | 4.993 | 0.7196 | | 66.1% | 12.2% | 10.63 | 0.6724 | | 27.9% | 4.9% |
| | | | | | Average | 52.6% | 14.1% | | | Average | 15.4% | 9.9% |
| | | | | | Score | 1 | 0 | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 379.1 | 0.5561 | 1172 | 0.6689 | | 209.2% | 20.3% | 441.3 | 0.617 | | 16.4% | 11.0% |
| Fall rate | -208.7 | -0.5586 | -415 | -0.6271 | | 98.9% | 12.3% | -203.9 | -0.6179 | | 2.3% | 10.6% |
| Number of reversals | 59.9 | 0.1543 | 73.67 | 0.3138 | | 23.0% | 103.4% | 52.67 | 0.2964 | | 12.1% | 92.1% |
| | | | | | Average | 110.3% | 45.3% | | | Average | 10.3% | 37.9% |
| | | | | | Score | 2 | 0 | | | Score | 0 | 0 |
| | | | | Total Point | | 3 | | | Total Point | | 0 | |
| | | | | Classification | | 2 | | | Classification | | 1 | |
| | | | | note: | Low risk of impact | | | | note: | Un-impacted condition | | |

Table 6.36 summarizes the comparative scores, made through the qualitative comparison of both annual median flow duration curves at 7 control points.

Table 6.36 Comparative Evaluation of Annual Median Flow Duration Curve for the Neches WAM

| CP | Data Period | Comparative Score USGS vs. MDNF | Comparative Score USGS vs. DDNF |
|---|---|---|---|
| Total | | 7 | 7 |
| MUJA | 01/01/1940-12/31/1960 | 1 | 1 |
| ANLU | 01/01/1940-12/31/1960 | 1 | 1 |
| NENE | 01/01/1940-12/31/1960 | 1 | 1 |
| NEDI | 01/01/1940-12/31/1960 | 1 | 1 |
| NERO | 01/01/1940-12/31/1960 | 1 | 1 |
| VIKO | 01/01/1940-12/31/1960 | 1 | 1 |
| NEEV | 01/01/1940-12/31/1960 | 1 | 1 |

Annual flow duration curves of each flow at all the seven control points are practically very similar as shown in Figures 6.10 to 6.16, respectively. This indicates both the disaggregated flows have very similar hydrologic state to the USGS daily recorded flows at the same sites for the drought and flood years.

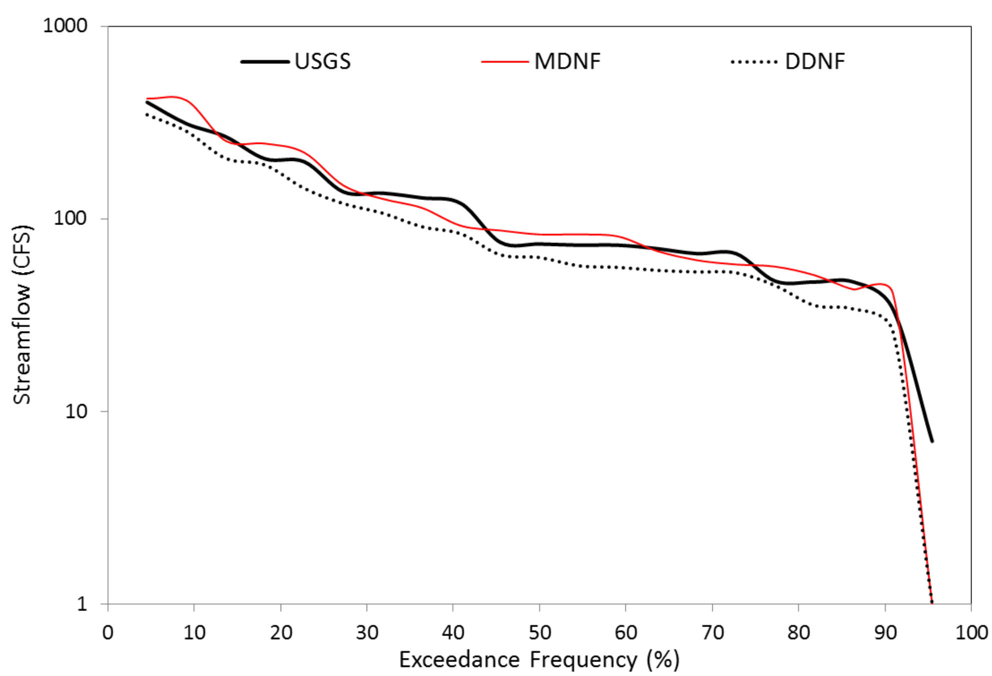



Figure 6.10 Annual Median Flow Duration Curves at MUJA

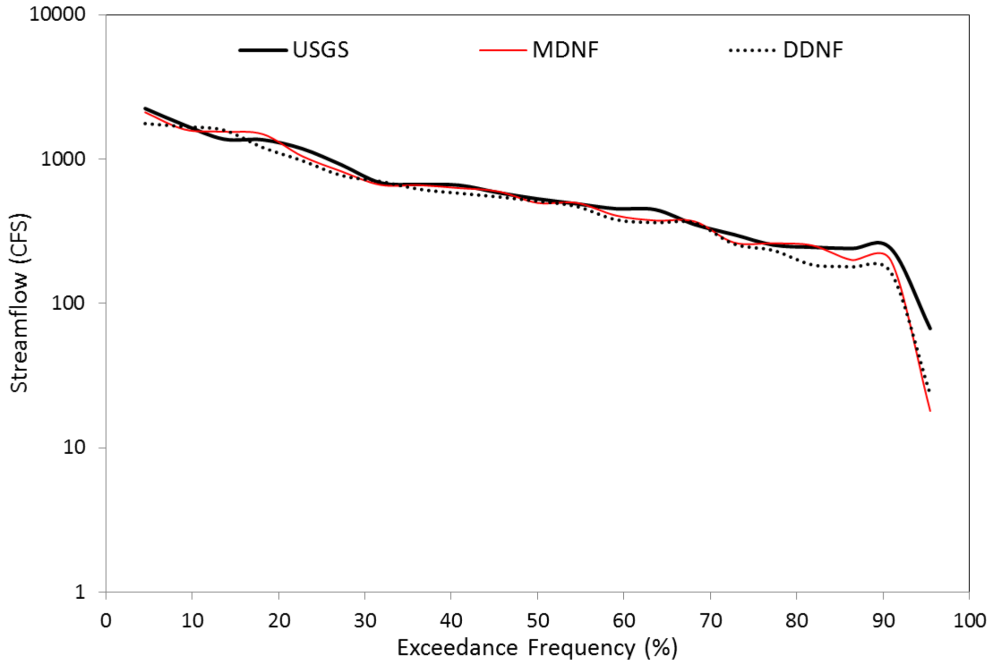



Figure 6.11 Annual Median Flow Duration Curves at ANLU

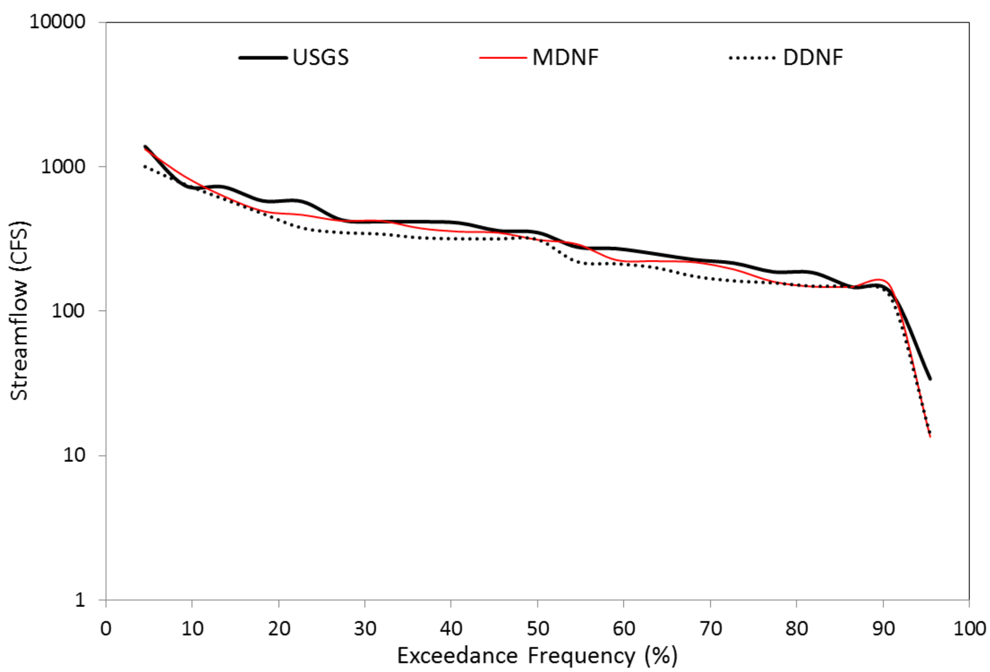



Figure 6.12 Annual Median Flow Duration Curves at NENE

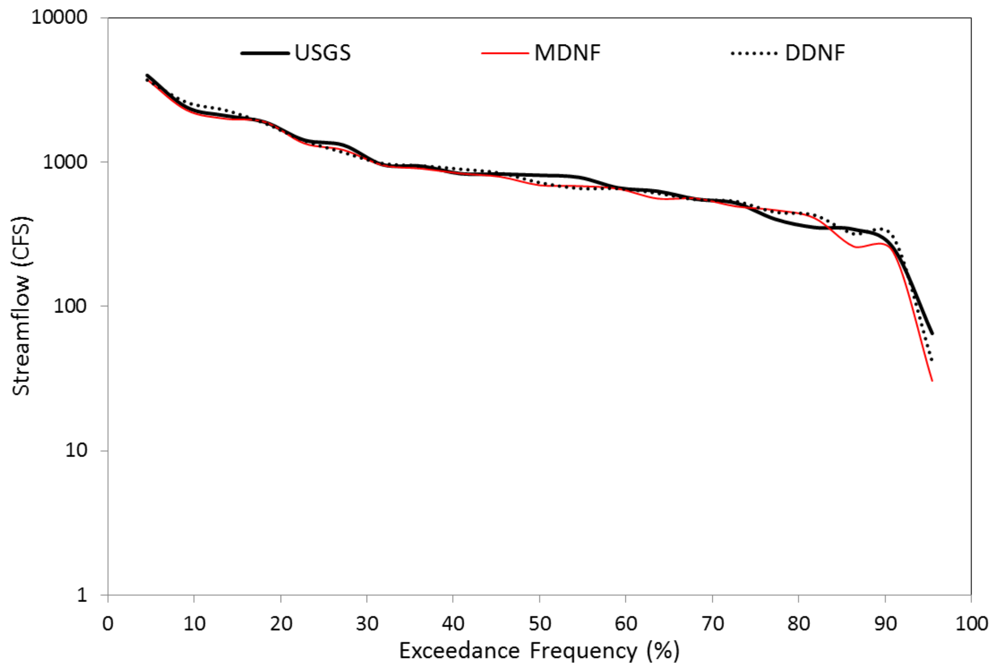



Figure 6.13 Annual Median Flow Duration Curves at NEDI

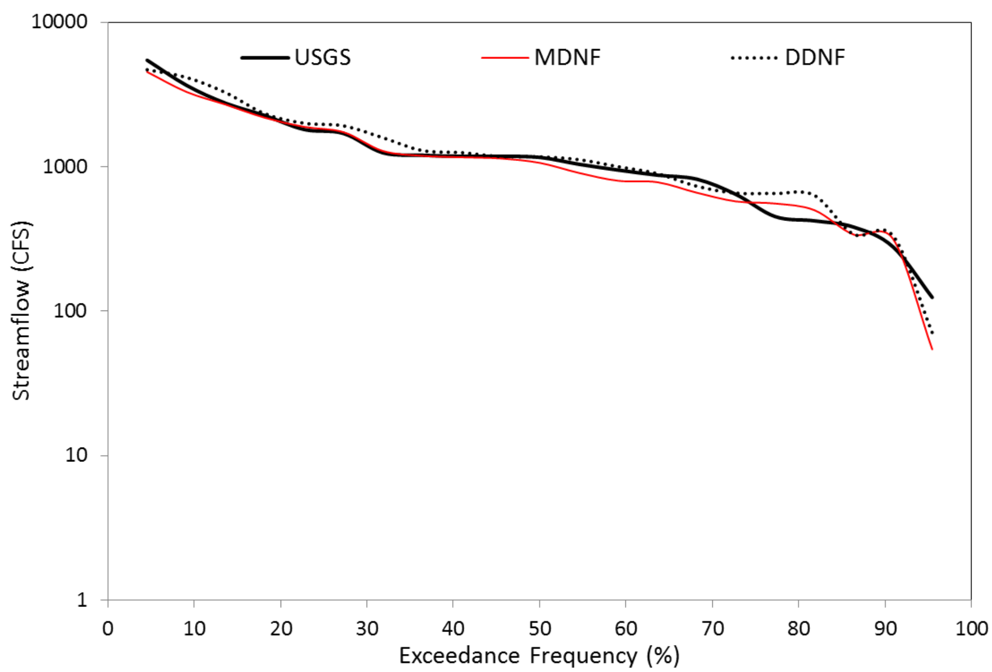



Figure 6.14 Annual Median Flow Duration Curves at NERO

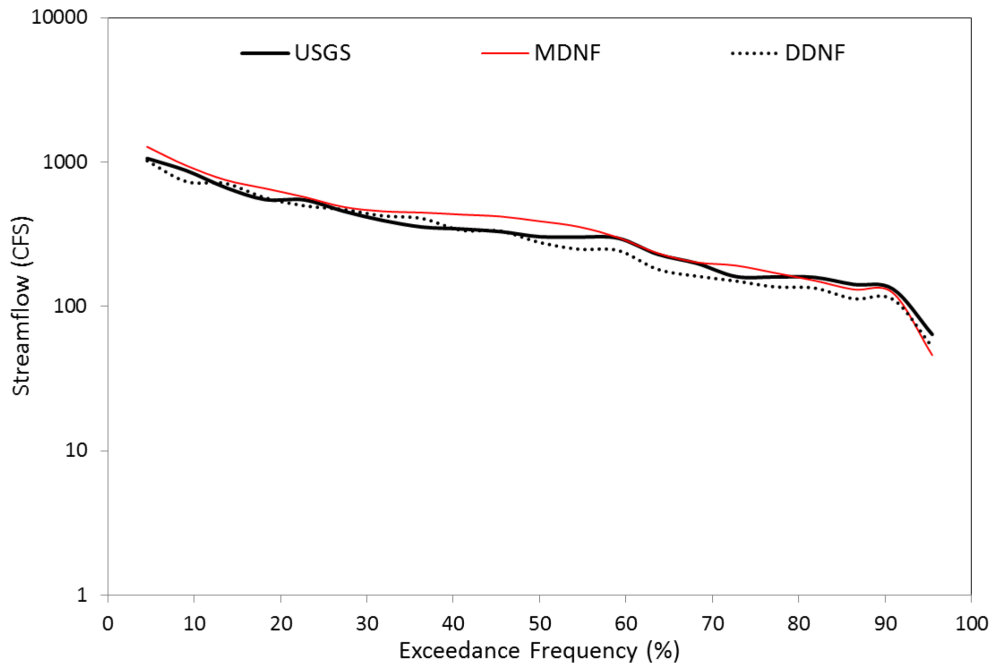



Figure 6.15 Annual Median Flow Duration Curves at VIKO

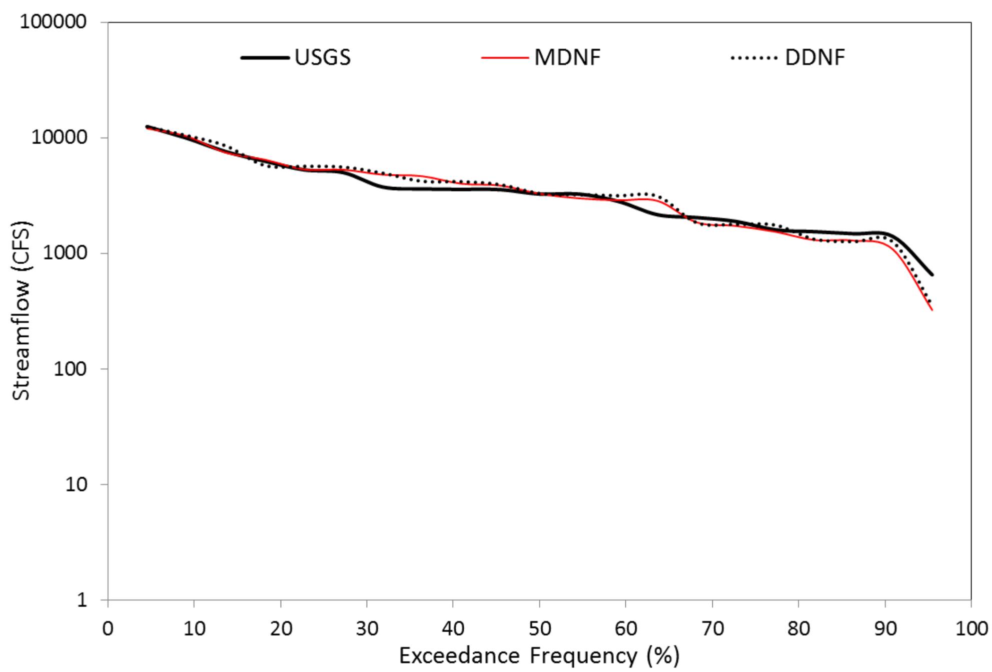



Figure 6.16 Annual Median Flow Duration Curves at NEEV

The total scores are the same through the comparison of both the flows as tabulated in Table 6.37. On a closer view, DDNF overwhelmingly outperforms than MDNF on statistic (NSE), while MDNF has slightly better performance than DDNF on DHRAM evaluation. Both disaggregated daily flow sequences have similar performance on the qualitative evaluation like flow frequency metrics and median annual flow duration curves like the Sabine WAM. Accordingly, the calibration strategy with USGS daily recorded flows for the daily SWAT model is selected for the daily Neches WAM.

Table 6.37 Selection of Calibration Strategy for the Neches WAM

| Methods | Evaluation purposes | Calibration Strategy | |
|---|---|---|---|
| | | Monthly WAM datasets | Daily USGS recorded data |
| Total Score | | 4 | 4 |
| Statistic Evaluation (NSE) | Streamflow timing | 0 | 2 |
| Flow Frequency Metric | Streamflow regime | 1 | 1 |
| DHRAM (IHA) | Hydrologic characteristics alteration | 2 | 0 |
| Median Annual Flow Duration Curve | Overall hydrologic state of a river | 1 | 1 |

6.4.3 GSA River Basins

NSE values of MDNF and DDNF are computed based on the USGS recorded flows at the 12 control points, and the comparative scores are made through the comparison of both the NSEs at a control point as listed in Table 6.38. MDNF outperforms DDNF on NSE evaluation at 8 out of the 12 control points in total. But, NSE values of DDNF are higher than MDNF at the 2 control points CP35 and CP37. MDNF has unacceptable value of NSE (NSE<0) at the 2 control points, CP15 and CP18 while DDNF has the unacceptable value at the 3 control points, CP15, CP18, and CP28, respectively. Total comparative scores are 18 for MDNF, and 6 for DDNF, respectively.

Table 6.38 Comparative Evaluation of Nash-Sutcliffe Efficiency for the GSA WAM

| CP | Data Period | NSE | | Comparative Score | |
|---|---|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF | USGS vs. MDNF | USGS vs. DDNF |
| Total | | | | 18 | 6 |
| CP01 | 06/01/1939-12/31/1960 | 0.49 | 0.28 | 2 | 0 |
| CP02 | 01/01/1934-12/31/1960 | 0.66 | 0.23 | 2 | 0 |
| CP04 | 01/01/1934-12/31/1960 | 0.61 | 0.54 | 2 | 0 |
| CP08 | 01/01/1934-12/31/1960 | 0.72 | 0.08 | 2 | 0 |
| CP10 | 05/01/1939-12/31/1960 | 0.53 | 0.38 | 2 | 0 |
| CP11 | 01/01/1934-12/31/1960 | 0.40 | 0.37 | 2 | 0 |
| CP15 | 01/01/1934-12/31/1960 | -0.47 | -0.66 | 1 | 1 |
| CP18 | 03/01/1939-12/31/1960 | -4.45 | -2.45 | 1 | 1 |
| CP28 | 08/01/1939-12/31/1960 | 0.20 | -0.35 | 2 | 0 |
| CP32 | 01/01/1934-12/31/1960 | 0.55 | 0.41 | 2 | 0 |
| CP35 | 01/01/1934-12/31/1960 | 0.53 | 0.57 | 0 | 2 |
| CP37 | 03/01/1939-12/31/1960 | 0.62 | 0.64 | 0 | 2 |

The three different flow frequency metrics of USGS daily recorded flows, MDNF, and DDNF at 12 control points are tabulated in Tables 6.39 to 6.42. Both mean flows of MDNF and DDNF are very similar to the mean flows of USGS daily recorded flows at all control points. Median (50% exceedance frequency) values of MDCF are also closely similar to the median flows of USGS daily recorded flows at all control points while median values of DDNF are underestimated than the value of the USGS flows. Minimum values of both MDNF and DDNF are almost similar to the USGS flows. Maximum values of DDNF are mostly similar to USGS daily recorded flows except for CP11. However, maximum values of DDNF are greatly variable depending on the control points

Maximum values of DDNF are more similar to USGS daily recorded flows than MDNF, but overall flow regimes of MDNF are more identical to the USGS flows than DDNF at control points CP01, CP02 and CP04. This indicates that MDNFs are better than DDNF on the evaluation of flow frequency metric at control points CP01, CP02 and CP04.

Table 6.39 Flow Frequency Metrics for Control Points CP01, CP02, and CP04

| | CP01 (CFS) | | | CP02 (CFS) | | | CP04 (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 143.3 | 143.7 | 143.7 | 284.0 | 284.4 | 284.4 | 381.0 | 372.8 | 372.8 |
| Std Dev | 488.9 | 344.1 | 609.6 | 1,158 | 820.2 | 1,576 | 1,258 | 835.2 | 1,366 |
| Min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Max | 25,300 | 10,281 | 22,230 | 66,100 | 30,855 | 65,049 | 52,300 | 28,635 | 53,913 |
| 0.1% | 6,900 | 5,306 | 10,323 | 14,137 | 12,011 | 27,102 | 19,252 | 10,712 | 17,397 |
| 0.2% | 4,307 | 3,806 | 7,137 | 9,752 | 6,771 | 13,878 | 9,181 | 7,886 | 12,549 |
| 0.5% | 2,081 | 1,703 | 2,787 | 4,205 | 3,603 | 6,582 | 5,051 | 4,694 | 7,184 |
| 1% | 1,291 | 1,226 | 1,685 | 2,685 | 2,478 | 3,552 | 3,070 | 3,194 | 4,808 |
| 2% | 732.0 | 827.8 | 973.0 | 1,697 | 1,640 | 1,892.0 | 2,017 | 2,116 | 3,055 |
| 5% | 414.0 | 499.1 | 468.0 | 852.0 | 973 | 897.0 | 1,160 | 1,311 | 1,352 |
| 10% | 270.0 | 325.0 | 269.0 | 550.0 | 648 | 487.0 | 794.0 | 906.0 | 758.0 |
| 15% | 200.0 | 250.0 | 187.0 | 396.0 | 486.0 | 345.0 | 589.0 | 673.0 | 530.0 |
| 20% | 165.0 | 202.0 | 143.0 | 314.0 | 376.0 | 250.0 | 479.0 | 532.0 | 392.0 |
| 30% | 121.0 | 130.0 | 88.0 | 220.0 | 240.0 | 144.0 | 334.0 | 341.0 | 227.0 |
| 40% | 90.0 | 84.0 | 56.0 | 157.0 | 158.0 | 89.0 | 235.0 | 215.0 | 137.0 |
| 50% | 67.0 | 57.0 | 36.0 | 106.0 | 106.0 | 55.0 | 163.0 | 141.0 | 88.0 |
| 60% | 50.0 | 36.0 | 24.0 | 77.0 | 71.0 | 33.0 | 105.0 | 91.0 | 53.0 |
| 70% | 37.0 | 21.0 | 14.0 | 58.0 | 43.0 | 17.0 | 78.0 | 55.0 | 28.0 |
| 80% | 27.0 | 9.0 | 7.0 | 40.0 | 24.0 | 8.0 | 49.0 | 30.0 | 10.0 |
| 85% | 20.0 | 5.0 | 5.0 | 29.0 | 16.0 | 4.0 | 36.0 | 21.0 | 4.0 |
| 90% | 12.0 | 2.0 | 2.0 | 18.0 | 8.0 | 1.0 | 23.0 | 11.0 | 0.0 |
| 95% | 2.0 | 1.0 | 1.0 | 4.0 | 2.0 | 0.0 | 11.0 | 3.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 |
| 99.5% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.8% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.9% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Maximum values of MDNF are more similar to USGS daily recorded flows than MDNF, but overall flow regimes of both MDNF and DDNF are identical to the USGS flows at control points CP08. Maximum values of both MDNF and DDNF are similar to USGS daily recorded flows, but overall flow regime of MDNF is more similar to the USGS flows than DDNF at the control points CP10. Maximum values of both MDNF and DDNF are underestimated than USGS daily recorded flows, and overall flow regimes of both MDNF and DDNF are similar to the USGS flows than DDNF at he control points CP11. These mean that MDNFs are the same as DDNFs at the control points CP08 and CP11, but MDNF is better than DDNF at the control point CP10.

Table 6.40 Flow Frequency Metrics for Control Points CP08, CP10 and CP11

| | CP08 (CFS) | | | CP10 (CFS) | | | CP11 (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 115.7 | 115.7 | 115.7 | 333.5 | 321.9 | 321.9 | 95.8 | 94.9 | 94.9 |
| Std Dev | 507.9 | 483.4 | 736.9 | 840.8 | 725.5 | 928.2 | 696.1 | 499.9 | 521.0 |
| Min | 0.7 | 0.0 | 0.0 | 43.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Max | 36,900 | 36,965 | 40,670 | 25,000 | 22,214 | 24,272 | 43,800 | 19,517 | 18,906 |
| 0.1% | 4,833 | 3,740 | 10,473 | 12,800 | 9,063 | 11,471 | 9,306 | 5,986 | 6,281 |
| 0.2% | 3,564 | 2,645 | 4,751 | 10,716 | 7,079 | 9,657 | 5,983 | 4,543 | 4,712 |
| 0.5% | 1,874 | 1,303 | 1,620 | 5,031 | 4,693 | 5,947 | 3,541 | 2,692 | 2,728 |
| 1% | 1,110 | 1,013 | 818.0 | 3,068 | 2,905 | 4,051 | 2,180 | 1,823 | 1,706 |
| 2% | 667.7 | 691.4 | 563.0 | 1,597 | 1,961 | 2,873 | 1,047 | 1,057 | 1,031 |
| 5% | 380.0 | 449.8 | 339.0 | 843.0 | 1,111 | 1,556 | 298.8 | 387.8 | 397.7 |
| 10% | 244.7 | 291.1 | 213.0 | 585.0 | 776.3 | 802.0 | 64.0 | 160.0 | 153.0 |
| 15% | 172.0 | 202.0 | 157.0 | 466.0 | 573.0 | 507.0 | 37.0 | 81.0 | 72.0 |
| 20% | 133.0 | 147.9 | 120.0 | 368.0 | 446.0 | 334.0 | 27.0 | 44.0 | 39.0 |
| 30% | 83.0 | 85.8 | 79.0 | 272.0 | 287.0 | 164.0 | 16.0 | 17.0 | 13.0 |
| 40% | 53.0 | 50.8 | 55.0 | 210.0 | 188.0 | 86.0 | 10.0 | 8.0 | 5.0 |
| 50% | 39.0 | 32.7 | 36.0 | 170.0 | 122.0 | 45.0 | 8.0 | 4.0 | 2.0 |
| 60% | 26.0 | 21.8 | 24.0 | 138.0 | 80.0 | 21.0 | 5.2 | 2.0 | 1.0 |
| 70% | 18.0 | 13.7 | 15.0 | 111.0 | 47.0 | 9.0 | 4.0 | 1.0 | 0.0 |
| 80% | 13.0 | 8.5 | 8.0 | 94.0 | 23.0 | 2.0 | 2.0 | 0.0 | 0.0 |
| 85% | 11.0 | 6.3 | 4.0 | 87.0 | 13.0 | 0.0 | 2.0 | 0.0 | 0.0 |
| 90% | 8.6 | 4.1 | 1.0 | 80.0 | 6.0 | 0.0 | 1.0 | 0.0 | 0.0 |
| 95% | 7.0 | 1.6 | 0.0 | 73.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 5.5 | 0.0 | 0.0 | 62.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 4.0 | 0.0 | 0.0 | 56.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.5% | 2.5 | 0.0 | 0.0 | 52.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.8% | 1.4 | 0.0 | 0.0 | 49.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.9% | 0.9 | 0.0 | 0.0 | 48.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Maximum values of both MDNF and DDNF are underestimated than USGS daily recorded flows, but overall flow regimes of MDNF more identical to the USGS flows than DDNF at the control point CP15. Maximum value of MDNF is overestimated than USGS daily recorded flows, and maximum value of DDNF is almost similar to the USGS flows at the control point 18. However, overall flow regimes of both MDNF and DDNF are totally different from the USGS flows at the control point 18. Maximum values of both MDNF and DDNF are similar to USGS daily recorded flows, but overall flow regimes of MDNF more similar to the USGS flows than DDNF at the control point CP28. In conclusion, MDNFs is better than DDNFs at the control points 15 and 28, but both are the same at the control point 18.

Table 6.41 Flow Frequency Metrics for Control Points CP15, CP18, and CP28

| | CP15 (CFS) | | | CP18 (CFS) | | | CP28 (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 1,619 | 1,533 | 1,533 | 43.3 | 35.8 | 35.8 | 103.1 | 173.2 | 173.2 |
| Std Dev | 3,602 | 2,650 | 3,106 | 61.2 | 151.6 | 121.3 | 375.8 | 417.2 | 542.4 |
| Min | 5.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 3.0 | 2.0 | 0.0 |
| Max | 129,000 | 48,176 | 62,687 | 2,690 | 3,562 | 2,680 | 15,900 | 14,291 | 15,441 |
| 0.1% | 40,019 | 27,830 | 34,098 | 612.3 | 2,069 | 1,619 | 5,040 | 5,074 | 6,767 |
| 0.2% | 30,455 | 24,869 | 27,544 | 549.1 | 1,729 | 1,215 | 3,557 | 4,142 | 5,439 |
| 0.5% | 22,000 | 17,609 | 18,338 | 323.8 | 960.3 | 781.8 | 1,569 | 2,518 | 3,189 |
| 1% | 16,700 | 12,752 | 14,197 | 210.2 | 695.8 | 594.9 | 1,040 | 1,925 | 2,594 |
| 2% | 10,800 | 9,503 | 10,338 | 156.0 | 421.4 | 351.4 | 604.5 | 1,207 | 1,660 |
| 5% | 5,128 | 5,470 | 6,007 | 131.0 | 155.0 | 167.1 | 277.0 | 592.8 | 729.8 |
| 10% | 2,887 | 3,496 | 3,684 | 102.0 | 65.0 | 87.0 | 148.0 | 335.5 | 377.0 |
| 15% | 2,160 | 2,588 | 2,588 | 83.3 | 34.0 | 52.0 | 113.0 | 251.0 | 247.0 |
| 20% | 1,720 | 2,021 | 2,002 | 67.0 | 21.0 | 31.0 | 97.0 | 200.0 | 175.0 |
| 30% | 1,320 | 1,410 | 1,338 | 43.0 | 9.0 | 14.0 | 82.0 | 139.0 | 94.0 |
| 40% | 1,040 | 1,049 | 903.0 | 30.0 | 2.0 | 5.0 | 72.0 | 106.0 | 55.0 |
| 50% | 824.0 | 768.0 | 590.0 | 24.0 | 0.0 | 1.0 | 60.0 | 79.0 | 29.0 |
| 60% | 680.0 | 551.0 | 370.0 | 21.0 | 0.0 | 0.0 | 42.0 | 57.0 | 15.0 |
| 70% | 555.0 | 364.0 | 220.0 | 16.0 | 0.0 | 0.0 | 23.0 | 38.0 | 6.0 |
| 80% | 388.0 | 231.0 | 111.0 | 12.0 | 0.0 | 0.0 | 14.0 | 21.0 | 2.0 |
| 85% | 310.0 | 163.0 | 70.0 | 11.0 | 0.0 | 0.0 | 12.0 | 15.0 | 1.0 |
| 90% | 188.0 | 104.0 | 36.0 | 9.0 | 0.0 | 0.0 | 9.0 | 11.0 | 0.0 |
| 95% | 94.0 | 51.0 | 6.0 | 7.0 | 0.0 | 0.0 | 7.0 | 7.0 | 0.0 |
| 98% | 25.0 | 19.0 | 0.0 | 6.0 | 0.0 | 0.0 | 6.0 | 5.0 | 0.0 |
| 99% | 10.0 | 11.0 | 0.0 | 5.0 | 0.0 | 0.0 | 5.0 | 3.2 | 0.0 |
| 99.5% | 7.0 | 5.0 | 0.0 | 4.0 | 0.0 | 0.0 | 4.0 | 3.0 | 0.0 |
| 99.8% | 5.0 | 1.0 | 0.0 | 4.0 | 0.0 | 0.0 | 4.0 | 2.0 | 0.0 |
| 99.9% | 5.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 4.0 | 2.0 | 0.0 |

Maximum values of both MDNF and DDNF are similar to USGS daily recorded flows at the control points CP32, CP35, and CP37. Overall flow regimes of MDNF are better than DDNF at the control points CP32 and CP37, but, both are the same at the control point CP35.

Table 6.42 Flow Frequency Metrics for Control Points CP32, CP35, and CP37

| | CP32 (CFS) | | | CP35 (CFS) | | | CP37 (CFS) | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MDNF | DDNF | USGS | MDNF | DDNF | USGS | MDNF | DDNF |
| Mean | 345.0 | 346.9 | 346.9 | 118.7 | 118.8 | 118.8 | 572.1 | 568.4 | 568.4 |
| Std Dev | 885.7 | 651.6 | 823.0 | 689.8 | 401.2 | 492.5 | 1,579 | 1,151 | 1,417 |
| Min | 19.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 4.0 | 0.0 |
| Max | 42,200 | 12,868 | 17,652 | 20,900 | 10,159 | 12,386 | 32,000 | 16,141 | 26,413 |
| 0.1% | 12,141 | 7,713 | 9,633 | 10,482 | 5,794 | 7,081 | 23,404 | 13,783 | 18,576 |
| 0.2% | 9,147 | 6,328 | 7,828 | 6,686 | 3,866 | 4,733 | 15,513 | 11,222 | 13,416 |
| 0.5% | 5,044 | 4,368 | 5,530 | 4,447 | 2,390 | 2,947 | 10,622 | 8,492 | 10,125 |
| 1% | 3,277 | 3,312 | 3,939 | 2,425 | 1,810 | 2,178 | 7,800 | 6,274 | 7,233 |
| 2% | 2,050 | 2,221 | 2,545 | 1,040 | 1,074 | 1,220 | 4,889 | 3,959 | 4,505 |
| 5% | 934.0 | 1,106 | 1,337 | 282.0 | 485.3 | 471.6 | 1,650 | 2,043 | 2,250 |
| 10% | 538.0 | 687.8 | 772.6 | 101.0 | 225.9 | 204.5 | 826.0 | 1,198.0 | 1,186 |
| 15% | 414.0 | 523.0 | 558.2 | 58.0 | 143.3 | 120.7 | 596.0 | 850.0 | 852.0 |
| 20% | 351.0 | 432.5 | 434.7 | 44.0 | 104.9 | 84.0 | 488.0 | 633.0 | 644.0 |
| 30% | 271.0 | 315.8 | 282.6 | 32.0 | 60.0 | 46.0 | 366.0 | 438.0 | 422.0 |
| 40% | 228.0 | 235.1 | 182.8 | 25.0 | 38.4 | 25.6 | 299.0 | 330.0 | 279.0 |
| 50% | 194.0 | 179.4 | 116.0 | 21.0 | 26.0 | 14.6 | 252.0 | 255.0 | 184.0 |
| 60% | 163.0 | 133.7 | 69.6 | 18.0 | 18.0 | 7.3 | 208.0 | 191.0 | 119.0 |
| 70% | 129.0 | 96.3 | 36.4 | 15.0 | 12.9 | 3.2 | 161.0 | 139.0 | 67.0 |
| 80% | 102.0 | 63.0 | 11.5 | 12.0 | 8.9 | 0.8 | 128.0 | 99.0 | 27.0 |
| 85% | 89.0 | 46.8 | 2.8 | 11.0 | 7.0 | 0.1 | 111.0 | 79.0 | 11.0 |
| 90% | 79.0 | 33.9 | 0.0 | 9.0 | 5.3 | 0.0 | 94.0 | 61.0 | 1.0 |
| 95% | 61.0 | 20.7 | 0.0 | 7.0 | 3.0 | 0.0 | 74.0 | 39.0 | 0.0 |
| 98% | 47.0 | 9.5 | 0.0 | 5.0 | 1.3 | 0.0 | 52.0 | 23.0 | 0.0 |
| 99% | 40.0 | 6.0 | 0.0 | 3.0 | 0.7 | 0.0 | 39.0 | 16.0 | 0.0 |
| 99.5% | 35.0 | 4.9 | 0.0 | 1.0 | 0.5 | 0.0 | 21.0 | 10.0 | 0.0 |
| 99.8% | 28.0 | 3.8 | 0.0 | 0.0 | 0.2 | 0.0 | 16.0 | 7.0 | 0.0 |
| 99.9% | 25.0 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 5.0 | 0.0 |

Table 6.43 summarizes the comparative scores, made through the qualitative comparison of both flow frequency metrics at the control points.

Table 6.43 Comparative Evaluation of Flow Frequency Metrics for the GSA WAM

| CP | Data Period | Comparative Score | |
|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF |
| Total | | 20 | 4 |
| CP01 | 06/01/1939-12/31/1960 | 2 | 0 |
| CP02 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP04 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP08 | 01/01/1934-12/31/1960 | 1 | 1 |
| CP10 | 05/01/1939-12/31/1960 | 2 | 0 |
| CP11 | 01/01/1934-12/31/1960 | 1 | 1 |
| CP15 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP18 | 03/01/1939-12/31/1960 | 1 | 1 |
| CP28 | 08/01/1939-12/31/1960 | 2 | 0 |
| CP32 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP35 | 01/01/1934-12/31/1960 | 1 | 1 |
| CP37 | 03/01/1939-12/31/1960 | 2 | 0 |

DHRAM method quantitatively evaluates how much the hydrologic characteristics of MDNF and DDNF are similar to or different from USGS daily recorded flows at 12 control points. Table 6.44 summarizes the scores of MDNF and DDNF based on the USGS daily recorded flows at 12 control points. Table 6.44 shows that MDNF has less impact points than DDNF at 10 of the 12 control points in total, and has the same points with DDNF at the control points, CP18 and CP37. This table also indicates that both MDNF and DDNF have slightly different hydrologic characteristics from USGS daily recorded flows at all the 12 control points.

Table 6.44 Impact points by the DHRAM Method for the GSA WAM

| CP | Data Period | Impact Points | |
|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF |
| Total | | 98 | 118 |
| CP01 | 06/01/1939-12/31/1960 | 7 | 8 |
| CP02 | 01/01/1934-12/31/1960 | 6 | 9 |
| CP04 | 01/01/1934-12/31/1960 | 7 | 8 |
| CP08 | 01/01/1934-12/31/1960 | 6 | 7 |
| CP10 | 05/01/1939-12/31/1960 | 8 | 11 |
| CP11 | 01/01/1934-12/31/1960 | 8 | 9 |
| CP15 | 01/01/1934-12/31/1960 | 9 | 11 |
| CP18 | 03/01/1939-12/31/1960 | 15 | 15 |
| CP28 | 08/01/1939-12/31/1960 | 9 | 15 |
| CP32 | 01/01/1934-12/31/1960 | 6 | 7 |
| CP35 | 01/01/1934-12/31/1960 | 9 | 10 |
| CP37 | 03/01/1939-12/31/1960 | 8 | 8 |

The detailed evaluation sheets for the 12 control points are tabulated in Tables 6.45 to 6.54. The evaluation sheets, tabulated in Tables 6.45, 6.46, and 6.47, commonly indicate that minimum flows of both MDNF and DDNF are underestimated than USGS daily recorded flows. The average of high pulse duration is considerably different between MDNF and the USGS flows while the average of low pulse duration is obviously different between DDNF and the USGS flows at the control points CP01, CP02 and CP04 that are located upstream of the Guadalupe River.

Table 6.45 Evaluation Sheet by DHRAM Method for Control Point CP01

| Control Point: | CP01 | Period: | 1939-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | MDNF | | | Absolute Chages | | DDNF | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 113.2 | 0.9421 | 115 | 0.9194 | | 1.6% | 2.4% | 114.9 | 0.9198 | | 1.5% | 2.4% |
| February | 154 | 1.037 | 155.8 | 1.018 | | 1.2% | 1.8% | 155.7 | 1.018 | | 1.1% | 1.8% |
| March | 143.4 | 0.9987 | 145.3 | 0.9778 | | 1.3% | 2.1% | 145.3 | 0.9783 | | 1.3% | 2.0% |
| April | 199.5 | 1.017 | 201.5 | 0.9998 | | 1.0% | 1.7% | 201.5 | 0.9998 | | 1.0% | 1.7% |
| May | 233.4 | 1.167 | 235.5 | 1.151 | | 0.9% | 1.4% | 235.5 | 1.152 | | 0.9% | 1.3% |
| June | 152.9 | 0.8769 | 153.7 | 0.8719 | | 0.5% | 0.6% | 153.7 | 0.8719 | | 0.5% | 0.6% |
| July | 76.65 | 0.6992 | 77.53 | 0.6894 | | 1.1% | 1.4% | 77.54 | 0.6889 | | 1.2% | 1.5% |
| August | 71.27 | 1.773 | 72.06 | 1.754 | | 1.1% | 1.1% | 72.08 | 1.753 | | 1.1% | 1.1% |
| September | 103.3 | 1.22 | 103.7 | 1.212 | | 0.4% | 0.7% | 103.7 | 1.212 | | 0.4% | 0.7% |
| October | 204.8 | 1.386 | 205 | 1.384 | | 0.1% | 0.1% | 205 | 1.385 | | 0.1% | 0.1% |
| November | 114.2 | 1.014 | 114.4 | 1.013 | | 0.2% | 0.1% | 114.3 | 1.013 | | 0.1% | 0.1% |
| December | 130.2 | 0.9825 | 130.2 | 0.982 | | 0.0% | 0.1% | 130.2 | 0.9821 | | 0.0% | 0.0% |
| | | | | | Average | 0.8% | 1.1% | | | Average | 0.8% | 1.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 20.41 | 0.9874 | 0.5909 | 1.93 | | 97.1% | 95.5% | 0.5909 | 1.623 | | 97.1% | 64.4% |
| 3-day minimum | 21.18 | 0.9717 | 0.7273 | 1.689 | | 96.6% | 73.8% | 0.7121 | 1.403 | | 96.6% | 44.4% |
| 7-day minimum | 22.74 | 0.9832 | 1.338 | 1.706 | | 94.1% | 73.5% | 1.078 | 1.419 | | 95.3% | 44.3% |
| 30-day minimum | 28.48 | 0.9251 | 11.04 | 1.406 | | 61.2% | 52.0% | 7.535 | 0.7511 | | 73.5% | 18.8% |
| 90-day minimum | 48.54 | 0.8482 | 49 | 0.8837 | | 0.9% | 4.2% | 45.43 | 0.9016 | | 6.4% | 6.3% |
| 1-day maximum | 5120 | 1.145 | 3255 | 0.8788 | | 36.4% | 23.2% | 6505 | 0.879 | | 27.1% | 23.2% |
| 3-day maximum | 2542 | 0.9565 | 1795 | 0.8127 | | 29.4% | 15.0% | 2990 | 0.8623 | | 17.6% | 9.8% |
| 7-day maximum | 1348 | 0.8574 | 1159 | 0.7554 | | 14.0% | 11.9% | 1594 | 0.8304 | | 18.2% | 3.1% |
| 30-day maximum | 496.9 | 0.7719 | 494.1 | 0.7703 | | 0.6% | 0.2% | 552.8 | 0.7792 | | 11.2% | 0.9% |
| 90-day maximum | 272.8 | 0.7155 | 277.2 | 0.7098 | | 1.6% | 0.8% | 284.6 | 0.7099 | | 4.3% | 0.8% |
| | | | | | Average | 43.2% | 35.0% | | | Average | 44.7% | 21.6% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 0 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 204.8 | 0.1372 | 144.5 | 0.2363 | | 29.4% | 72.2% | 135.1 | 0.2325 | | 34.0% | 69.5% |
| Date of maximum | 181.4 | 0.1945 | 177.3 | 0.2039 | | 2.3% | 4.8% | 171.2 | 0.2238 | | 5.6% | 15.1% |
| | | | | | Average | 15.9% | 38.5% | | | Average | 19.8% | 42.3% |
| | | | | | Score | 0 | 1 | | | Score | 0 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4.5 | 0.9837 | 6.545 | 0.5731 | | 45.4% | 41.7% | 8.5 | 0.4277 | | 88.9% | 56.5% |
| Low pulse duration | 17.72 | 0.7425 | 12.41 | 0.4822 | | 30.0% | 35.1% | 9.8 | 0.4537 | | 44.7% | 38.9% |
| High pulse count | 3.727 | 0.7414 | 3.545 | 0.7057 | | 4.9% | 4.8% | 4.864 | 0.6784 | | 30.5% | 8.5% |
| High pulse duration | 2.113 | 0.3375 | 4.234 | 0.7006 | | 100.4% | 107.6% | 1.816 | 0.4738 | | 14.1% | 40.4% |
| | | | | | Average | 45.2% | 47.3% | | | Average | 44.5% | 36.1% |
| | | | | | Score | 2 | 1 | | | Score | 2 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 137.4 | 0.7976 | 95.29 | 0.7988 | | 30.6% | 0.2% | 257 | 0.7273 | | 87.0% | 8.8% |
| Fall rate | -51.46 | -0.7438 | -33.75 | -0.6859 | | 34.4% | 7.8% | -75.99 | -0.7175 | | 47.7% | 3.5% |
| Number of reversals | 86.91 | 0.1602 | 57.91 | 0.2281 | | 33.4% | 42.4% | 79.27 | 0.2014 | | 8.8% | 25.7% |
| | | | | | Average | 32.8% | 16.8% | | | Average | 47.8% | 12.7% |
| | | | | | Score | 1 | 0 | | | Score | 2 | 0 |
| | | | | | Total Point | | 7 | | | Total Point | | 8 |
| | | | | | Classification | | 3 | | | Classification | | 3 |
| | | | | | note: | Moderate risk of impact | | | | note: | Moderate risk of impact | |

# Table 6.46 Evaluation Sheet by DHRAM Method for Control Point CP02

Control Point: CP02 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 225.2 | 1.1 | 225.4 | 1.099 | | 0.1% | 0.1% | 225.4 | 1.099 | | 0.1% | 0.1% |
| February | 272.7 | 1.168 | 272.8 | 1.167 | | 0.0% | 0.1% | 272.8 | 1.167 | | 0.0% | 0.1% |
| March | 267.9 | 1.123 | 268.1 | 1.121 | | 0.1% | 0.2% | 268.1 | 1.122 | | 0.1% | 0.1% |
| April | 335.2 | 1.144 | 335.6 | 1.142 | | 0.1% | 0.2% | 335.6 | 1.142 | | 0.1% | 0.2% |
| May | 460 | 1.126 | 460.3 | 1.125 | | 0.1% | 0.1% | 460.3 | 1.125 | | 0.1% | 0.1% |
| June | 426.4 | 1.782 | 427 | 1.779 | | 0.1% | 0.2% | 427 | 1.779 | | 0.1% | 0.2% |
| July | 174.3 | 1.33 | 174.9 | 1.324 | | 0.3% | 0.5% | 174.9 | 1.324 | | 0.3% | 0.5% |
| August | 104.9 | 1.46 | 105.5 | 1.453 | | 0.6% | 0.5% | 105.5 | 1.453 | | 0.6% | 0.5% |
| September | 395 | 2.152 | 395.4 | 2.15 | | 0.1% | 0.1% | 395.4 | 2.15 | | 0.1% | 0.1% |
| October | 324.9 | 1.365 | 325.1 | 1.364 | | 0.1% | 0.1% | 325.1 | 1.364 | | 0.1% | 0.1% |
| November | 201.9 | 1.151 | 202 | 1.15 | | 0.0% | 0.1% | 202 | 1.15 | | 0.0% | 0.1% |
| December | 227.3 | 0.9571 | 227.4 | 0.9568 | | 0.0% | 0.0% | 227.4 | 0.9568 | | 0.0% | 0.0% |
| | | | | | Average | 0.1% | 0.2% | | | Average | 0.1% | 0.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 35.52 | 0.9015 | 3.915 | 1.682 | | 89.0% | 86.6% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 36.37 | 0.9006 | 4.748 | 1.616 | | 86.9% | 79.4% | 0.02469 | 3.603 | | 99.9% | 300.1% |
| 7-day minimum | 38.25 | 0.9035 | 7.844 | 1.764 | | 79.5% | 95.2% | 0.2011 | 2.079 | | 99.5% | 130.1% |
| 30-day minimum | 47.92 | 0.8804 | 32.55 | 1.015 | | 32.1% | 15.3% | 10.48 | 1.366 | | 78.1% | 55.2% |
| 90-day minimum | 81.29 | 0.9154 | 82.02 | 0.9638 | | 0.9% | 5.3% | 72.73 | 1.003 | | 10.5% | 9.6% |
| 1-day maximum | 10280 | 1.484 | 6683 | 1.342 | | 35.0% | 9.6% | 15850 | 1.162 | | 54.2% | 21.7% |
| 3-day maximum | 5388 | 1.265 | 3862 | 1.294 | | 28.3% | 2.3% | 7237 | 1.197 | | 34.3% | 5.4% |
| 7-day maximum | 2915 | 1.122 | 2470 | 1.186 | | 15.3% | 5.7% | 3652 | 1.086 | | 25.3% | 3.2% |
| 30-day maximum | 1122 | 1.051 | 1102 | 1.05 | | 1.8% | 0.1% | 1206 | 0.9979 | | 7.5% | 5.1% |
| 90-day maximum | 602.6 | 0.9058 | 596.8 | 0.903 | | 1.0% | 0.3% | 622.1 | 0.9007 | | 3.2% | 0.6% |
| | | | | | Average | 37.0% | 30.0% | | | Average | 51.3% | 63.1% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 203.9 | 0.1904 | 160 | 0.2248 | | 21.5% | 18.1% | 118 | 0.2218 | | 42.1% | 16.5% |
| Date of maximum | 182.6 | 0.2395 | 170.4 | 0.214 | | 6.7% | 10.6% | 176.4 | 0.229 | | 3.4% | 4.4% |
| | | | | | Average | 14.1% | 14.4% | | | Average | 22.8% | 10.4% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4.037 | 0.9382 | 6.593 | 0.6201 | | 63.3% | 33.9% | 7.556 | 0.4158 | | 87.2% | 55.7% |
| Low pulse duration | 19.83 | 0.7788 | 12.63 | 0.6983 | | 36.3% | 10.3% | 11.67 | 0.4766 | | 41.1% | 38.8% |
| High pulse count | 3.407 | 0.9037 | 2.296 | 0.9496 | | 32.6% | 5.1% | 4.556 | 0.8851 | | 33.7% | 2.1% |
| High pulse duration | 2.297 | 0.5707 | 5.576 | 0.7008 | | 142.8% | 22.8% | 1.556 | 0.3678 | | 32.3% | 35.6% |
| | | | | | Average | 68.7% | 18.0% | | | Average | 48.6% | 33.0% |
| | | | | | Score | 3 | 0 | | | Score | 2 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 310.3 | 1.053 | 147 | 1.137 | | 52.6% | 8.0% | 502.5 | 0.9616 | | 61.9% | 8.7% |
| Fall rate | -94.93 | -1.094 | -54.31 | -1.042 | | 42.8% | 4.8% | -178.5 | -0.9036 | | 88.0% | 17.4% |
| Number of reversals | 75.63 | 0.1886 | 64.63 | 0.1212 | | 14.5% | 35.7% | 75.52 | 0.1901 | | 0.1% | 0.8% |
| | | | | | Average | 36.7% | 16.2% | | | Average | 50.0% | 9.0% |
| | | | | | Score | 1 | 0 | | | Score | 2 | 0 |

| | | | |
|---|---|---|---|
| Total Point | 6 | Total Point | 9 |
| Classification | 3 | Classification | 3 |
| note: | Moderate risk of impact | note: | Moderate risk of impact |

# Table 6.47 Evaluation Sheet by DHRAM Method for Control Point CP04

Control Point: CP04 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 314.3 | 1.088 | 306.7 | 1.112 | | 2.4% | 2.2% | 306.7 | 1.112 | | 2.4% | 2.2% |
| February | 368.2 | 1.088 | 360.7 | 1.106 | | 2.0% | 1.7% | 360.7 | 1.106 | | 2.0% | 1.7% |
| March | 374.3 | 1.07 | 366.7 | 1.087 | | 2.0% | 1.6% | 366.7 | 1.087 | | 2.0% | 1.6% |
| April | 449.9 | 1.096 | 442 | 1.113 | | 1.8% | 1.6% | 441.9 | 1.113 | | 1.8% | 1.6% |
| May | 589.8 | 1.107 | 581.7 | 1.12 | | 1.4% | 1.2% | 581.7 | 1.12 | | 1.4% | 1.2% |
| June | 533.3 | 1.623 | 525.1 | 1.648 | | 1.5% | 1.5% | 525.1 | 1.648 | | 1.5% | 1.5% |
| July | 267.9 | 1.406 | 259.7 | 1.443 | | 3.1% | 2.6% | 259.7 | 1.443 | | 3.1% | 2.6% |
| August | 150.2 | 1.299 | 141.7 | 1.374 | | 5.7% | 5.8% | 141.7 | 1.375 | | 5.7% | 5.9% |
| September | 503.3 | 1.909 | 494.7 | 1.943 | | 1.7% | 1.8% | 494.6 | 1.943 | | 1.7% | 1.8% |
| October | 425.4 | 1.283 | 416.5 | 1.312 | | 2.1% | 2.3% | 416.5 | 1.312 | | 2.1% | 2.3% |
| November | 285.8 | 1.191 | 276.9 | 1.228 | | 3.1% | 3.1% | 276.9 | 1.228 | | 3.1% | 3.1% |
| December | 317.4 | 0.9681 | 309.6 | 0.9891 | | 2.5% | 2.2% | 309.6 | 0.9891 | | 2.5% | 2.2% |
| | | | | | Average | 2.4% | 2.3% | | | Average | 2.4% | 2.3% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 56.59 | 0.9031 | 5.93 | 1.83 | | 89.5% | 102.2% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 57.44 | 0.9051 | 7.20 | 1.66 | | 87.5% | 83.1% | 0.012 | 5.196 | | 100.0% | 474.1% |
| 7-day minimum | 59.93 | 0.9102 | 12.07 | 1.76 | | 79.9% | 93.1% | 0.291 | 2.523 | | 99.5% | 177.2% |
| 30-day minimum | 73.72 | 0.8857 | 43.79 | 1.05 | | 40.6% | 18.7% | 14.86 | 1.29 | | 79.8% | 45.6% |
| 90-day minimum | 118.2 | 0.8834 | 111.20 | 0.98 | | 5.9% | 11.2% | 98.78 | 0.9969 | | 16.4% | 12.8% |
| 1-day maximum | 10930 | 1.299 | 5260.00 | 1.33 | | 51.9% | 2.5% | 12460 | 1.177 | | 14.0% | 9.4% |
| 3-day maximum | 6277 | 1.247 | 4160.00 | 1.24 | | 33.7% | 0.7% | 7226 | 1.075 | | 15.1% | 13.8% |
| 7-day maximum | 3459 | 1.087 | 2928.00 | 1.12 | | 15.4% | 3.2% | 4315 | 0.9913 | | 24.7% | 8.8% |
| 30-day maximum | 1402 | 0.9639 | 1374.00 | 0.97 | | 2.0% | 0.1% | 1511 | 0.9263 | | 7.8% | 3.9% |
| 90-day maximum | 788.2 | 0.8443 | 771.40 | 0.85 | | 2.1% | 0.4% | 805.5 | 0.848 | | 2.2% | 0.4% |
| | | | | | Average | 40.8% | 31.5% | | | Average | 46.0% | 84.6% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 218.8 | 0.2055 | 152 | 0.2333 | | 30.5% | 13.5% | 102.9 | 0.2095 | | 53.0% | 1.9% |
| Date of maximum | 185.7 | 0.2595 | 180.7 | 0.2292 | | 2.7% | 11.7% | 171.4 | 0.2347 | | 7.7% | 9.6% |
| | | | | | Average | 16.6% | 12.6% | | | Average | 30.3% | 5.8% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 3.111 | 1.299 | 5.333 | 0.686 | | 71.4% | 47.2% | 7.593 | 0.4387 | | 144.1% | 66.2% |
| Low pulse duration | 32.46 | 0.9283 | 15.03 | 0.6472 | | 53.7% | 30.3% | 11.35 | 0.434 | | 65.0% | 53.2% |
| High pulse count | 3.37 | 0.8715 | 2.778 | 0.9951 | | 17.6% | 14.2% | 4.074 | 0.8636 | | 20.9% | 0.9% |
| High pulse duration | 2.744 | 0.5501 | 6.848 | 0.4423 | | 149.6% | 19.6% | 3.046 | 0.4195 | | 11.0% | 23.7% |
| | | | | | Average | 73.1% | 27.8% | | | Average | 60.2% | 36.0% |
| | | | | | Score | 3 | 0 | | | Score | 2 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 337.6 | 1.092 | 128.1 | 0.9568 | | 62.1% | 12.4% | 400.3 | 0.9231 | | 18.6% | 15.5% |
| Fall rate | -98.77 | -1.024 | -48.05 | -0.869 | | 51.4% | 15.1% | -137.4 | -0.8373 | | 39.1% | 18.2% |
| Number of reversals | 77.81 | 0.1695 | 60.37 | 0.153 | | 22.4% | 9.7% | 70.63 | 0.1497 | | 9.2% | 11.7% |
| | | | | | Average | 45.3% | 12.4% | | | Average | 22.3% | 15.1% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 0 |
| | | | | | Total Point | | 7 | | | Total Point | | 8 |
| | | | | | Classification | | 3 | | | Classification | | 3 |
| | | | | | note: | Moderate risk of impact | | | | note: | Moderate risk of impact | |

The minimum flows and low pulse durations of both MDNF and DDNF are underestimated while both the occurrence numbers of low pulse are overestimated than the USGS flows at the control points CP08 and CP10 as tabulated in Tables 6.48 and 6.49.

Table 6.48 Evaluation Sheet by DHRAM Method for Control Point CP08

Control Point: CP08 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 94.35 | 1.183 | 94.33 | 1.183 | | 0.0% | 0.0% | 94.33 | 1.183 | | 0.0% | 0.0% |
| February | 124.9 | 1.2 | 124.9 | 1.2 | | 0.0% | 0.0% | 124.9 | 1.2 | | 0.0% | 0.0% |
| March | 135.5 | 1.193 | 135.5 | 1.193 | | 0.0% | 0.0% | 135.5 | 1.193 | | 0.0% | 0.0% |
| April | 175 | 1.209 | 175.1 | 1.209 | | 0.1% | 0.0% | 175.1 | 1.209 | | 0.1% | 0.0% |
| May | 181.8 | 1.334 | 181.9 | 1.334 | | 0.1% | 0.0% | 181.9 | 1.334 | | 0.1% | 0.0% |
| June | 137.8 | 1.326 | 137.8 | 1.326 | | 0.0% | 0.0% | 137.8 | 1.326 | | 0.0% | 0.0% |
| July | 69.37 | 1.595 | 69.36 | 1.595 | | 0.0% | 0.0% | 69.39 | 1.595 | | 0.0% | 0.0% |
| August | 37.25 | 0.8768 | 37.24 | 0.8785 | | 0.0% | 0.2% | 37.26 | 0.8782 | | 0.0% | 0.2% |
| September | 134.6 | 2.09 | 134.5 | 2.09 | | 0.1% | 0.0% | 134.5 | 2.09 | | 0.1% | 0.0% |
| October | 108.9 | 1.595 | 108.9 | 1.595 | | 0.0% | 0.0% | 108.9 | 1.596 | | 0.0% | 0.1% |
| November | 90.71 | 1.424 | 90.69 | 1.425 | | 0.0% | 0.1% | 90.68 | 1.425 | | 0.0% | 0.1% |
| December | 101.5 | 1.241 | 101.5 | 1.242 | | 0.0% | 0.1% | 101.5 | 1.242 | | 0.0% | 0.1% |
| | | | | | Average | 0.0% | 0.0% | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 15.59 | 0.7717 | 2.189 | 1.185 | | 86.0% | 53.6% | 1.741 | 2.512 | | 88.8% | 225.5% |
| 3-day minimum | 15.95 | 0.7614 | 2.375 | 1.173 | | 85.1% | 54.1% | 2.284 | 2.466 | | 85.7% | 223.9% |
| 7-day minimum | 16.64 | 0.7489 | 3.104 | 1.229 | | 81.3% | 64.1% | 2.852 | 2.244 | | 82.9% | 199.6% |
| 30-day minimum | 19.2 | 0.7163 | 8.504 | 0.8047 | | 55.7% | 12.3% | 10.47 | 1.098 | | 45.5% | 53.3% |
| 90-day minimum | 29.26 | 0.8612 | 27.75 | 0.9032 | | 5.2% | 4.9% | 27.47 | 0.891 | | 6.1% | 3.5% |
| 1-day maximum | 4985 | 1.452 | 4128 | 1.801 | | 17.2% | 24.0% | 8752 | 1.169 | | 75.6% | 19.5% |
| 3-day maximum | 2274 | 1.206 | 2150 | 1.361 | | 5.5% | 12.9% | 3253 | 1.095 | | 43.1% | 9.2% |
| 7-day maximum | 1257 | 1.055 | 1222 | 1.127 | | 2.8% | 6.8% | 1528 | 1.007 | | 21.6% | 4.5% |
| 30-day maximum | 477.9 | 0.8241 | 472 | 0.8028 | | 1.2% | 2.6% | 494.2 | 0.8095 | | 3.4% | 1.8% |
| 90-day maximum | 264.6 | 0.7941 | 263.9 | 0.783 | | 0.3% | 1.4% | 267 | 0.7966 | | 0.9% | 0.3% |
| | | | | | Average | 34.0% | 23.7% | | | Average | 45.3% | 74.1% |
| | | | | | Score | 1 | 0 | | | Score | 2 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 219.3 | 0.266 | 279.9 | 0.3057 | | 27.6% | 14.9% | 137.8 | 0.2542 | | 37.2% | 4.4% |
| Date of maximum | 185.6 | 0.2422 | 173.1 | 0.2679 | | 6.7% | 10.6% | 179 | 0.2599 | | 3.6% | 7.3% |
| | | | | | Average | 17.2% | 12.8% | | | Average | 20.4% | 5.9% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 4 | 1.183 | 7.37 | 0.6971 | | 84.3% | 41.1% | 9.037 | 0.7737 | | 125.9% | 34.6% |
| Low pulse duration | 20.89 | 0.7651 | 11.04 | 0.4069 | | 47.2% | 46.8% | 9.436 | 0.5306 | | 54.8% | 30.6% |
| High pulse count | 3.593 | 0.911 | 2.259 | 0.7724 | | 37.1% | 15.2% | 2.259 | 0.8732 | | 37.1% | 4.1% |
| High pulse duration | 2.182 | 0.5113 | 4.079 | 0.6849 | | 86.9% | 34.0% | 1.512 | 0.5065 | | 30.7% | 0.9% |
| | | | | | Average | 63.9% | 34.3% | | | Average | 62.1% | 17.6% |
| | | | | | Score | 2 | 1 | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 189 | 1.059 | 67.32 | 1.281 | | 64.4% | 21.0% | 144.4 | 1.04 | | 23.6% | 1.8% |
| Fall rate | -53.24 | -0.9952 | -26.05 | -1.139 | | 51.1% | 14.4% | -65.32 | -0.9579 | | 22.7% | 3.7% |
| Number of reversals | 70.67 | 0.1352 | 90.07 | 0.1268 | | 27.5% | 6.2% | 84.74 | 0.1756 | | 19.9% | 29.9% |
| | | | | | Average | 47.6% | 13.9% | | | Average | 22.1% | 11.8% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 0 |
| | | | | | | | | | | | | |
| | | | Total Point | | | 6 | | | Total Point | | 7 | |
| | | | Classification | | | 3 | | | Classification | | 3 | |
| | | | note: | | Moderate risk of impact | | | | note: | Moderate risk of impact | | |

# Table 6.49 Evaluation Sheet by DHRAM Method for Control Point CP10

Control Point: CP10 Period: 1939-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 274.8 | 0.8497 | 271 | 0.8692 | | 1.4% | 2.3% | 268.5 | 0.8753 | | 2.3% | 3.0% |
| February | 358.2 | 1.034 | 354.4 | 1.047 | | 1.1% | 1.3% | 351.9 | 1.056 | | 1.8% | 2.1% |
| March | 343.4 | 0.9242 | 339.6 | 0.9351 | | 1.1% | 1.2% | 337.1 | 0.9425 | | 1.8% | 2.0% |
| April | 512.3 | 0.947 | 509.7 | 0.9479 | | 0.5% | 0.1% | 507.2 | 0.9546 | | 1.0% | 0.8% |
| May | 427.3 | 0.979 | 416.9 | 1.008 | | 2.4% | 3.0% | 416.9 | 1.008 | | 2.4% | 3.0% |
| June | 392 | 0.8379 | 382.5 | 0.8723 | | 2.4% | 4.1% | 382.5 | 0.8722 | | 2.4% | 4.1% |
| July | 224.6 | 0.8876 | 211.7 | 0.9521 | | 5.7% | 7.3% | 211.7 | 0.9523 | | 5.7% | 7.3% |
| August | 165.4 | 0.5871 | 151.5 | 0.6528 | | 8.4% | 11.2% | 151.5 | 0.6527 | | 8.4% | 11.2% |
| September | 328.1 | 1.231 | 316.1 | 1.292 | | 3.7% | 5.0% | 316.1 | 1.292 | | 3.7% | 5.0% |
| October | 354 | 1.061 | 344.5 | 1.115 | | 2.7% | 5.1% | 344.5 | 1.115 | | 2.7% | 5.1% |
| November | 293.9 | 0.8876 | 281.4 | 0.9392 | | 4.3% | 5.8% | 281.4 | 0.9391 | | 4.3% | 5.8% |
| December | 310.4 | 0.8937 | 298.9 | 0.9403 | | 3.7% | 5.2% | 298.9 | 0.9402 | | 3.7% | 5.2% |
| | | | | | Average | 3.1% | 4.3% | | | Average | 3.3% | 4.5% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 101.3 | 0.4697 | 1.227 | 2.011 | | 98.8% | 328.1% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 108.6 | 0.4296 | 1.606 | 1.889 | | 98.5% | 339.7% | 0 | 0 | | 100.0% | 100.0% |
| 7-day minimum | 113.1 | 0.4119 | 3.013 | 2.201 | | 97.3% | 434.4% | 0.01948 | 3.429 | | 100.0% | 732.5% |
| 30-day minimum | 121 | 0.4089 | 22.34 | 1.018 | | 81.5% | 149.0% | 9.994 | 1.412 | | 91.7% | 245.3% |
| 90-day minimum | 145.4 | 0.4777 | 116.9 | 0.5931 | | 19.6% | 24.2% | 111 | 0.5737 | | 23.7% | 20.1% |
| 1-day maximum | 8509 | 0.7891 | 6544 | 0.8043 | | 23.1% | 1.9% | 7728 | 0.7278 | | 9.2% | 7.8% |
| 3-day maximum | 4704 | 0.7619 | 4187 | 0.729 | | 11.0% | 4.3% | 5185 | 0.6848 | | 10.2% | 10.1% |
| 7-day maximum | 2582 | 0.7717 | 2757 | 0.726 | | 6.8% | 5.9% | 3200 | 0.6937 | | 23.9% | 10.1% |
| 30-day maximum | 1010 | 0.6812 | 1063 | 0.6497 | | 5.2% | 4.6% | 1106 | 0.6611 | | 9.5% | 3.0% |
| 90-day maximum | 615.3 | 0.6854 | 626.6 | 0.6593 | | 1.8% | 3.8% | 646.4 | 0.6836 | | 5.1% | 0.3% |
| | | | | | Average | 44.4% | 129.6% | | | Average | 47.3% | 122.9% |
| | | | | | Score | 2 | 2 | | | Score | 2 | 2 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 219.7 | 0.2805 | 158.6 | 0.2571 | | 27.8% | 8.3% | 95.23 | 0.2202 | | 56.7% | 21.5% |
| Date of maximum | 176.7 | 0.1774 | 158 | 0.158 | | 10.6% | 10.9% | 155.1 | 0.178 | | 12.2% | 0.3% |
| | | | | | Average | 19.2% | 9.6% | | | Average | 34.4% | 10.9% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 8.5 | 1.295 | 9 | 0.5676 | | 5.9% | 56.2% | 10.5 | 0.4406 | | 23.5% | 66.0% |
| Low pulse duration | 16.86 | 1.271 | 9.979 | 0.2988 | | 40.8% | 76.5% | 8.443 | 0.3157 | | 49.9% | 75.2% |
| High pulse count | 5.136 | 0.739 | 5.227 | 0.6678 | | 1.8% | 9.6% | 8.318 | 0.6526 | | 62.0% | 11.7% |
| High pulse duration | 1.829 | 0.3289 | 3.553 | 0.5056 | | 94.3% | 53.7% | 2.493 | 0.3996 | | 36.3% | 21.5% |
| | | | | | Average | 35.7% | 49.0% | | | Average | 42.9% | 43.6% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 263.3 | 0.8774 | 288.3 | 0.6094 | | 9.5% | 30.5% | 630.7 | 0.5039 | | 139.5% | 42.6% |
| Fall rate | -116.4 | -0.6698 | -70.66 | -0.5388 | | 39.3% | 19.6% | -135.7 | -0.5045 | | 16.6% | 24.7% |
| Number of reversals | 141.5 | 0.3499 | 63.55 | 0.1713 | | 55.1% | 51.0% | 75.23 | 0.1805 | | 46.8% | 48.4% |
| | | | | | Average | 34.6% | 33.7% | | | Average | 67.7% | 38.6% |
| | | | | | Score | 1 | 1 | | | Score | 3 | 1 |

| | DCFM | | DCFD | |
|---|---|---|---|---|
| Total Point | | 8 | | 11 |
| Classification | | 3 | | 4 |
| note: | Moderate risk of impact | | High risk of impat | |

The amounts and frequencies of low flow regimes of both MDNF and DDNF are slightly different from the USGS flows at the control point CP11 as tabulated in Table 6.50.

Table 6.50 Evaluation Sheet by DHRAM Method for Control Point CP11

Control Point: CP11 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 70.43 | 1.492 | 69.5 | 1.513 | | 1.3% | 1.4% | 69.52 | 1.512 | | 1.3% | 1.3% |
| February | 79.73 | 1.358 | 78.76 | 1.375 | | 1.2% | 1.3% | 78.73 | 1.375 | | 1.3% | 1.3% |
| March | 75.12 | 1.666 | 74.24 | 1.686 | | 1.2% | 1.2% | 74.24 | 1.686 | | 1.2% | 1.2% |
| April | 218.4 | 1.348 | 217.4 | 1.354 | | 0.5% | 0.4% | 217.4 | 1.354 | | 0.5% | 0.4% |
| May | 107.4 | 1.367 | 106.5 | 1.378 | | 0.8% | 0.8% | 106.5 | 1.379 | | 0.8% | 0.9% |
| June | 133.7 | 1.341 | 132.8 | 1.351 | | 0.7% | 0.7% | 132.8 | 1.35 | | 0.7% | 0.7% |
| July | 120.4 | 3.27 | 119.6 | 3.292 | | 0.7% | 0.7% | 119.6 | 3.292 | | 0.7% | 0.7% |
| August | 35.45 | 3.117 | 34.69 | 3.183 | | 2.1% | 2.1% | 34.7 | 3.182 | | 2.1% | 2.1% |
| September | 67.19 | 1.882 | 66.29 | 1.907 | | 1.3% | 1.3% | 66.32 | 1.906 | | 1.3% | 1.3% |
| October | 105.9 | 2.44 | 105.1 | 2.457 | | 0.8% | 0.7% | 105.1 | 2.457 | | 0.8% | 0.7% |
| November | 66.21 | 1.755 | 65.39 | 1.776 | | 1.2% | 1.2% | 65.38 | 1.776 | | 1.3% | 1.2% |
| December | 71.87 | 1.638 | 70.97 | 1.659 | | 1.3% | 1.3% | 70.98 | 1.658 | | 1.2% | 1.2% |
| | | | | | Average | 1.1% | 1.1% | | | Average | 1.1% | 1.1% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 1.778 | 1.096 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 1.914 | 1.085 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 7-day minimum | 2.074 | 1.055 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 30-day minimum | 2.736 | 1.013 | 0.7988 | 1.779 | | 70.8% | 75.6% | 0.3963 | 2.121 | | 85.5% | 109.4% |
| 90-day minimum | 10.66 | 1.5 | 9.986 | 1.858 | | 6.3% | 23.9% | 10.61 | 1.953 | | 0.5% | 30.2% |
| 1-day maximum | 7077 | 1.196 | 4872 | 1.059 | | 31.2% | 11.5% | 5363 | 0.9858 | | 24.2% | 17.6% |
| 3-day maximum | 3565 | 0.9818 | 2930 | 0.9104 | | 17.8% | 7.3% | 2966 | 0.8759 | | 16.8% | 10.8% |
| 7-day maximum | 1781 | 0.9028 | 1732 | 0.8129 | | 2.8% | 10.0% | 1693 | 0.7848 | | 4.9% | 13.1% |
| 30-day maximum | 540.8 | 0.8354 | 561.1 | 0.8269 | | 3.8% | 1.0% | 557.8 | 0.8234 | | 3.1% | 1.4% |
| 90-day maximum | 242.6 | 0.7835 | 240.7 | 0.7818 | | 0.8% | 0.2% | 240.6 | 0.7772 | | 0.8% | 0.8% |
| | | | | | Average | 43.3% | 42.9% | | | Average | 43.6% | 48.3% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 196.3 | 0.1566 | 61 | 0.1858 | | 68.9% | 18.6% | 19.11 | 0.05699 | | 90.3% | 63.6% |
| Date of maximum | 166.1 | 0.2462 | 153.4 | 0.2139 | | 7.6% | 13.1% | 155.6 | 0.2298 | | 6.3% | 6.7% |
| | | | | | Average | 38.3% | 15.9% | | | Average | 48.3% | 35.1% |
| | | | | | Score | 1 | 0 | | | Score | 2 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 5.481 | 1.001 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| Low pulse duration | 16.32 | 0.6613 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| High pulse count | 4.593 | 0.7716 | 3.852 | 0.7081 | | 16.1% | 8.2% | 4.185 | 0.744 | | 8.9% | 3.6% |
| High pulse duration | 1.928 | 0.4008 | 3.26 | 0.3425 | | 69.1% | 14.5% | 3.063 | 0.3461 | | 58.9% | 13.6% |
| | | | | | Average | 71.3% | 55.7% | | | Average | 66.9% | 54.3% |
| | | | | | Score | 3 | 1 | | | Score | 2 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 255.3 | 0.6601 | 231.4 | 0.8451 | | 9.4% | 28.0% | 315.9 | 0.7496 | | 23.7% | 13.6% |
| Fall rate | -127.7 | -0.6357 | -56.51 | -0.7951 | | 55.7% | 25.1% | -69.38 | -0.7144 | | 45.7% | 12.4% |
| Number of reversals | 70.89 | 0.2635 | 59.15 | 0.2731 | | 16.6% | 3.6% | 60.63 | 0.2774 | | 14.5% | 5.3% |
| | | | | | Average | 27.2% | 18.9% | | | Average | 28.0% | 10.4% |
| | | | | | Score | 1 | 0 | | | Score | 1 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Total Point | | 8 | Total Point | | 9 |
| Classification | | 3 | Classification | | 3 |
| note: | Moderate risk of impact | | note: | Moderate risk of impact | |

Amounts of monthly flows and daily minimum flows of both MDNF and DDNF are underestimated than the USGS flows. The Flow frequencies of both MDNF and DDNF also slightly different from the USGS flows at the control point CP15 as tabulated in Table 6.51. These are attributed to effluent from spring water sources within the basin.

Table 6.51 Evaluation Sheet by DHRAM Method for Control Point CP15

Control Point: CP15 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 1468 | 1.144 | 1207 | 0.8742 | | 17.8% | 23.6% | 1207 | 0.8742 | | 17.8% | 23.6% |
| February | 1365 | 0.8685 | 1462 | 1.129 | | 7.1% | 30.0% | 1462 | 1.129 | | 7.1% | 30.0% |
| March | 1251 | 0.8689 | 1380 | 0.8469 | | 10.3% | 2.5% | 1380 | 0.8469 | | 10.3% | 2.5% |
| April | 1556 | 1.093 | 1770 | 0.8974 | | 13.8% | 17.9% | 1770 | 0.8974 | | 13.8% | 17.9% |
| May | 1389 | 0.8571 | 2567 | 1.109 | | 84.8% | 29.4% | 2567 | 1.109 | | 84.8% | 29.4% |
| June | 2111 | 1.001 | 1857 | 1.028 | | 12.0% | 2.7% | 1857 | 1.028 | | 12.0% | 2.7% |
| July | 2468 | 1.023 | 1870 | 1.957 | | 24.2% | 91.3% | 1870 | 1.958 | | 24.2% | 91.4% |
| August | 2130 | 0.9649 | 580.7 | 0.7362 | | 72.7% | 23.7% | 580.7 | 0.7362 | | 72.7% | 23.7% |
| September | 1568 | 1.703 | 1363 | 1.133 | | 13.1% | 33.5% | 1363 | 1.133 | | 13.1% | 33.5% |
| October | 798.1 | 0.7083 | 1697 | 1.338 | | 112.6% | 88.9% | 1697 | 1.338 | | 112.6% | 88.9% |
| November | 1503 | 1.092 | 1418 | 1.323 | | 5.7% | 21.2% | 1418 | 1.323 | | 5.7% | 21.2% |
| December | 1796 | 1.302 | 1232 | 0.9331 | | 31.4% | 28.3% | 1232 | 0.9331 | | 31.4% | 28.3% |
| | | | | | Average | 33.8% | 32.7% | | | Average | 33.8% | 32.8% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 1 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 358.7 | 0.6177 | 68.74 | 1.107 | | 80.8% | 79.2% | 4.185 | 2.463 | | 98.8% | 298.7% |
| 3-day minimum | 385.1 | 0.6021 | 76.32 | 1.073 | | 80.2% | 78.2% | 6.877 | 2.404 | | 98.2% | 299.3% |
| 7-day minimum | 403.3 | 0.6004 | 90.42 | 1.054 | | 77.6% | 75.5% | 16.03 | 2.336 | | 96.0% | 289.1% |
| 30-day minimum | 465.4 | 0.6071 | 238 | 0.7826 | | 48.9% | 28.9% | 147.7 | 0.8664 | | 68.3% | 42.7% |
| 90-day minimum | 617.6 | 0.6149 | 509.3 | 0.6684 | | 17.5% | 8.7% | 486.2 | 0.6935 | | 21.3% | 12.8% |
| 1-day maximum | 25110 | 1.043 | 12540 | 0.9193 | | 50.1% | 11.9% | 15870 | 0.9086 | | 36.8% | 12.9% |
| 3-day maximum | 20650 | 1.042 | 11670 | 0.904 | | 43.5% | 13.2% | 14420 | 0.9256 | | 30.2% | 11.2% |
| 7-day maximum | 14280 | 0.9476 | 10410 | 0.8888 | | 27.1% | 6.2% | 12490 | 0.9297 | | 12.5% | 1.9% |
| 30-day maximum | 5650 | 0.797 | 5395 | 0.8532 | | 4.5% | 7.1% | 5624 | 0.8434 | | 0.5% | 5.8% |
| 90-day maximum | 3126 | 0.7162 | 3120 | 0.758 | | 0.2% | 5.8% | 3169 | 0.7486 | | 1.4% | 4.5% |
| | | | | | Average | 43.0% | 31.5% | | | Average | 46.4% | 97.9% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 2 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 309.4 | 0.1777 | 192.8 | 0.2344 | | 37.7% | 31.9% | 155.4 | 0.2659 | | 49.8% | 49.6% |
| Date of maximum | 210.3 | 0.2703 | 159.9 | 0.2031 | | 24.0% | 24.9% | 157.3 | 0.2119 | | 25.2% | 21.6% |
| | | | | | Average | 30.8% | 28.4% | | | Average | 37.5% | 35.6% |
| | | | | | Score | 1 | 0 | | | Score | 1 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 5.481 | 1.189 | 4.889 | 0.5739 | | 10.8% | 51.7% | 8.741 | 0.3894 | | 59.5% | 67.2% |
| Low pulse duration | 17.39 | 0.7503 | 18.16 | 1.029 | | 4.4% | 37.1% | 9.595 | 0.5909 | | 44.8% | 21.2% |
| High pulse count | 4.185 | 0.8768 | 3 | 0.8165 | | 28.3% | 6.9% | 4.333 | 0.8321 | | 3.5% | 5.1% |
| High pulse duration | 4.287 | 0.4809 | 8.526 | 0.621 | | 98.9% | 29.1% | 6.129 | 0.3641 | | 43.0% | 24.3% |
| | | | | | Average | 35.6% | 31.2% | | | Average | 37.7% | 29.5% |
| | | | | | Score | 1 | 1 | | | Score | 1 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 538.9 | 0.8099 | 305.6 | 0.7324 | | 43.3% | 9.6% | 503.9 | 0.6751 | | 6.5% | 16.6% |
| Fall rate | -369.5 | -0.7123 | -143.6 | -0.6956 | | 61.1% | 2.3% | -247.2 | -0.6234 | | 33.1% | 12.5% |
| Number of reversals | 152.1 | 0.1857 | 52 | 0.1402 | | 65.8% | 24.5% | 62.93 | 0.1175 | | 58.6% | 36.7% |
| | | | | | Average | 56.7% | 12.1% | | | Average | 32.7% | 22.0% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 0 |

| | DCFM | DCFD |
|---|---|---|
| Total Point | 9 | 11 |
| Classification | 3 | 4 |
| note: | Moderate risk of impact | High risk of impat |

Hydrological characteristics of both MDNF and DDNF are totally different from the USGS flows at the control point CP18 as tabulated in Table 6.52. The control point CP18 is located on San Antonio River at San Antonio city. These differences may be attributed to various water uses in San Antonio city.

Table 6.52 Evaluation Sheet by DHRAM Method for Control Point CP18

Control Point: CP18 Period: 1939-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 43.65 | 0.9154 | 32.81 | 0.8811 | | 24.8% | 3.7% | 32.83 | 0.8804 | | 24.8% | 3.8% |
| February | 47.5 | 0.8501 | 36.27 | 0.8138 | | 23.6% | 4.3% | 36.3 | 0.8131 | | 23.6% | 4.4% |
| March | 45.81 | 0.8384 | 36.85 | 0.7262 | | 19.6% | 13.4% | 36.87 | 0.7261 | | 19.5% | 13.4% |
| April | 51.96 | 0.8076 | 44.61 | 0.7576 | | 14.1% | 6.2% | 44.64 | 0.7574 | | 14.1% | 6.2% |
| May | 50.65 | 0.7464 | 43.33 | 0.6792 | | 14.5% | 9.0% | 43.38 | 0.6779 | | 14.4% | 9.2% |
| June | 41.65 | 0.7527 | 35.56 | 0.6754 | | 14.6% | 10.3% | 35.59 | 0.6752 | | 14.5% | 10.3% |
| July | 30.93 | 0.7331 | 26.15 | 0.6695 | | 15.5% | 8.7% | 26.17 | 0.6696 | | 15.4% | 8.7% |
| August | 27.33 | 0.5282 | 21.87 | 0.5534 | | 20.0% | 4.8% | 21.9 | 0.5533 | | 19.9% | 4.8% |
| September | 43.39 | 1.123 | 38.33 | 1.134 | | 11.7% | 1.0% | 38.37 | 1.133 | | 11.6% | 0.9% |
| October | 48.74 | 0.9988 | 41.73 | 0.9836 | | 14.4% | 1.5% | 41.77 | 0.9831 | | 14.3% | 1.6% |
| November | 44.04 | 1 | 34.66 | 0.992 | | 21.3% | 0.8% | 34.69 | 0.9917 | | 21.2% | 0.8% |
| December | 44.96 | 0.9032 | 34.89 | 0.8693 | | 22.4% | 3.8% | 34.92 | 0.8682 | | 22.3% | 3.9% |
| | | | | | Average | 18.0% | 5.6% | | | Average | 18.0% | 5.7% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 12.09 | 0.598 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 13.77 | 0.5207 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 7-day minimum | 14.75 | 0.4858 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| 30-day minimum | 17.3 | 0.4497 | 1.23 | 1.771 | | 92.9% | 293.8% | 1.686 | 1.713 | | 90.3% | 280.9% |
| 90-day minimum | 23.46 | 0.5636 | 14.93 | 0.7231 | | 36.4% | 28.3% | 15.04 | 0.709 | | 35.9% | 25.8% |
| 1-day maximum | 502.9 | 1.059 | 1469 | 0.5749 | | 192.1% | 45.7% | 1057 | 0.6394 | | 110.2% | 39.6% |
| 3-day maximum | 276.1 | 1.065 | 618.2 | 0.6348 | | 123.9% | 40.4% | 540 | 0.6326 | | 95.6% | 40.6% |
| 7-day maximum | 161.9 | 0.9241 | 305.8 | 0.6953 | | 88.9% | 24.8% | 292.3 | 0.7025 | | 80.5% | 24.0% |
| 30-day maximum | 92.55 | 0.77 | 106.7 | 0.6314 | | 15.3% | 18.0% | 105.9 | 0.6489 | | 14.4% | 15.7% |
| 90-day maximum | 72.72 | 0.7446 | 67.32 | 0.6496 | | 7.4% | 12.8% | 67.65 | 0.6536 | | 7.0% | 12.2% |
| | | | | | Average | 85.7% | 76.4% | | | Average | 73.4% | 73.9% |
| | | | | | Score | 3 | 1 | | | Score | 3 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 186.5 | 0.345 | 4.273 | 0.01753 | | 97.7% | 94.9% | 5.591 | 0.02164 | | 97.0% | 93.7% |
| Date of maximum | 203.5 | 0.2472 | 208.6 | 0.2364 | | 2.5% | 4.4% | 200.1 | 0.2673 | | 1.7% | 8.1% |
| | | | | | Average | 50.1% | 49.6% | | | Average | 49.3% | 50.9% |
| | | | | | Score | 2 | 1 | | | Score | 2 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 10.82 | 1.159 | 0 | 0 | | 100.0% | 100.0% | 0 | 0 | | 100.0% | 100.0% |
| Low pulse duration | 6.025 | 0.78 | | | | 100.0% | 100.0% | | | | 100.0% | 100.0% |
| High pulse count | 5.773 | 0.7483 | 10.95 | 0.4268 | | 89.7% | 43.0% | 10.73 | 0.4171 | | 85.9% | 44.3% |
| High pulse duration | 4.895 | 1.626 | 1.298 | 0.2279 | | 73.5% | 86.0% | 1.669 | 0.3232 | | 65.9% | 80.1% |
| | | | | | Average | 90.8% | 82.2% | | | Average | 87.9% | 81.1% |
| | | | | | Score | 3 | 1 | | | Score | 3 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 15.58 | 0.6559 | 192.1 | 0.486 | | 1133.0% | 25.9% | 148.1 | 0.5124 | | 850.6% | 21.9% |
| Fall rate | -12.49 | -0.5248 | -55.18 | -0.4824 | | 341.8% | 8.1% | -36.89 | -0.4925 | | 195.4% | 6.2% |
| Number of reversals | 159.8 | 0.09928 | 64.32 | 0.189 | | 59.7% | 90.4% | 64.27 | 0.187 | | 59.8% | 88.4% |
| | | | | | Average | 511.5% | 41.5% | | | Average | 368.6% | 38.8% |
| | | | | | Score | 3 | 1 | | | Score | 3 | 1 |

| | DCFM | | DCFD |
|---|---|---|---|
| Total Point | 15 | Total Point | 15 |
| Classification | 4 | Classification | 4 |
| note: | High risk of impat | note: | High risk of impat |

Monthly flows of both MDNF and DDNF are greater than the USGS flows at the control point CP28. The daily minimum flows of both MDNF and DDNF are smaller, and the daily maximum flows of both are bigger than the USGS flows at the control point as tabulated in Table 6.53. The control point CP 28 is located downstream of Median Lake. Thus, these differences are attributed to the operation of Medina Lake.

Table 6.53 Evaluation Sheet by DHRAM Method for Control Point CP28

| Control Point: | CP28 | Period: | 1939-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 76.5 | 0.7758 | 126.8 | 1.103 | | 65.8% | 42.2% | 125.9 | 1.115 | | 64.6% | 43.7% |
| February | 105.8 | 0.8571 | 183 | 1.217 | | 73.0% | 42.0% | 182.1 | 1.227 | | 72.1% | 43.2% |
| March | 67.26 | 0.5605 | 150.2 | 1.06 | | 123.3% | 89.1% | 149.4 | 1.071 | | 122.1% | 91.1% |
| April | 108.3 | 1.099 | 225.8 | 1.232 | | 108.5% | 12.1% | 225 | 1.24 | | 107.8% | 12.8% |
| May | 110.2 | 1.051 | 246.7 | 1.071 | | 123.9% | 1.9% | 245.9 | 1.078 | | 123.1% | 2.6% |
| June | 98.64 | 0.9636 | 203.4 | 1.078 | | 106.2% | 11.9% | 202.6 | 1.086 | | 105.4% | 12.7% |
| July | 66.62 | 0.8886 | 93.78 | 0.8432 | | 40.8% | 5.1% | 92.89 | 0.8587 | | 39.4% | 3.4% |
| August | 85.65 | 1.996 | 114.4 | 1.618 | | 33.6% | 18.9% | 114.4 | 1.618 | | 33.6% | 18.9% |
| September | 171.7 | 1.539 | 217.5 | 1.394 | | 26.7% | 9.4% | 217.5 | 1.394 | | 26.7% | 9.4% |
| October | 143.1 | 1.311 | 215.1 | 1.096 | | 50.3% | 16.4% | 215.2 | 1.096 | | 50.4% | 16.4% |
| November | 98.37 | 1.567 | 137.2 | 1.236 | | 39.5% | 21.1% | 137.2 | 1.236 | | 39.5% | 21.1% |
| December | 84.74 | 0.7497 | 127.7 | 0.8431 | | 50.7% | 12.5% | 127.7 | 0.8434 | | 50.7% | 12.5% |
| | | | | | Average | 70.2% | 23.6% | | | Average | 69.6% | 24.0% |
| | | | | | Score | 3 | 0 | | | Score | 3 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 28.55 | 0.8148 | 14 | 0.9682 | | 51.0% | 18.8% | 0.2273 | 2.325 | | 99.2% | 185.3% |
| 3-day minimum | 29.5 | 0.802 | 15.29 | 0.9309 | | 48.2% | 16.1% | 0.303 | 1.793 | | 99.0% | 123.6% |
| 7-day minimum | 30.97 | 0.7782 | 17.43 | 0.9218 | | 43.7% | 18.5% | 0.6948 | 2.352 | | 97.8% | 202.2% |
| 30-day minimum | 36.12 | 0.6979 | 33.46 | 0.7622 | | 7.4% | 9.2% | 10.23 | 1.631 | | 71.7% | 133.7% |
| 90-day minimum | 48.36 | 0.747 | 70.1 | 1.071 | | 45.0% | 43.4% | 64.9 | 1.165 | | 34.2% | 56.0% |
| 1-day maximum | 2904 | 1.29 | 3267 | 1.057 | | 12.5% | 18.1% | 4032 | 1.009 | | 38.8% | 21.8% |
| 3-day maximum | 1608 | 1.153 | 2156 | 0.9362 | | 34.1% | 18.8% | 2653 | 0.8456 | | 65.0% | 26.7% |
| 7-day maximum | 892.2 | 1.105 | 1329 | 0.8811 | | 49.0% | 20.3% | 1621 | 0.8339 | | 81.7% | 24.5% |
| 30-day maximum | 330.6 | 1.083 | 527.2 | 0.854 | | 59.5% | 21.1% | 586.7 | 0.8379 | | 77.5% | 22.6% |
| 90-day maximum | 201.1 | 1.024 | 324.1 | 0.8545 | | 61.2% | 16.6% | 336.6 | 0.8515 | | 67.4% | 16.8% |
| | | | | | Average | 41.1% | 20.1% | | | Average | 73.2% | 81.3% |
| | | | | | Score | 1 | 0 | | | Score | 3 | 1 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 160.2 | 0.2979 | 184 | 0.2522 | | 14.9% | 15.3% | 82.09 | 0.2495 | | 48.8% | 16.2% |
| Date of maximum | 272.5 | 0.2651 | 172.8 | 0.2576 | | 36.6% | 2.8% | 180.5 | 0.2549 | | 33.8% | 3.8% |
| | | | | | Average | 25.7% | 9.1% | | | Average | 41.3% | 10.0% |
| | | | | | Score | 1 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 5.182 | 1.382 | 4.318 | 0.8254 | | 16.7% | 40.3% | 9.545 | 0.4943 | | 84.2% | 64.2% |
| Low pulse duration | 15.03 | 0.6441 | 19.46 | 0.8618 | | 29.5% | 33.8% | 8.287 | 0.4431 | | 44.9% | 31.2% |
| High pulse count | 3.455 | 0.8223 | 4.955 | 0.8775 | | 43.4% | 6.7% | 6.318 | 0.7987 | | 82.9% | 2.9% |
| High pulse duration | 2.208 | 0.7815 | 3.091 | 0.6221 | | 40.0% | 20.4% | 2.564 | 0.4578 | | 16.1% | 41.4% |
| | | | | | Average | 32.4% | 25.3% | | | Average | 57.0% | 34.9% |
| | | | | | Score | 1 | 0 | | | Score | 2 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 83.77 | 1.061 | 184.2 | 1.066 | | 119.9% | 0.5% | 245.2 | 0.8168 | | 192.7% | 23.0% |
| Fall rate | -46.33 | -0.9528 | -40.32 | -0.857 | | 13.0% | 10.1% | -74.57 | -0.8258 | | 61.0% | 13.3% |
| Number of reversals | 107.6 | 0.1877 | 66.09 | 0.3783 | | 38.6% | 101.5% | 76.27 | 0.3275 | | 29.1% | 74.5% |
| | | | | | Average | 57.1% | 37.4% | | | Average | 94.3% | 36.9% |
| | | | | | Score | 2 | 1 | | | Score | 3 | 1 |

| DCFM | | DCFD | |
|---|---|---|---|
| Total Point | 9 | Total Point | 15 |
| Classification | 3 | Classification | 4 |
| note: | Moderate risk of impact | note: | High risk of impat |

Both MDNF and DDNF have underestimated minimum flows, and have different flow frequency characteristics than the USGS flows at the control points CP32 and CP37 as tabulated in Table 6.54 and 6.55. These are also attributed to the influence of Median Lake operation even though the two control points are far away from the Lake.

Table 6.54 Evaluation Sheet by DHRAM Method for Control Point CP32

Control Point: CP32 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 274.2 | 0.6211 | 267.9 | 0.838 | | 2.3% | 34.9% | 267.9 | 0.838 | | 2.3% | 34.9% |
| February | 298.4 | 0.7345 | 312.4 | 0.9713 | | 4.7% | 32.2% | 312.4 | 0.9713 | | 4.7% | 32.2% |
| March | 244.1 | 0.4548 | 258.7 | 0.6947 | | 6.0% | 52.7% | 258.7 | 0.6948 | | 6.0% | 52.8% |
| April | 358.7 | 0.7867 | 389.5 | 0.9733 | | 8.6% | 23.7% | 389.5 | 0.9733 | | 8.6% | 23.7% |
| May | 440.4 | 0.9502 | 464 | 0.9322 | | 5.4% | 1.9% | 464 | 0.9322 | | 5.4% | 1.9% |
| June | 487.5 | 1.417 | 470.8 | 1.191 | | 3.4% | 15.9% | 470.8 | 1.191 | | 3.4% | 15.9% |
| July | 342 | 1.477 | 306.8 | 1.434 | | 10.3% | 2.9% | 306.8 | 1.434 | | 10.3% | 2.9% |
| August | 211.1 | 0.7619 | 188.5 | 0.94 | | 10.7% | 23.4% | 188.5 | 0.94 | | 10.7% | 23.4% |
| September | 519.9 | 1.6 | 581.4 | 1.678 | | 11.8% | 4.9% | 581.4 | 1.678 | | 11.8% | 4.9% |
| October | 402.6 | 1.022 | 403.3 | 1.081 | | 0.2% | 5.8% | 403.3 | 1.081 | | 0.2% | 5.8% |
| November | 291.3 | 0.9003 | 275.1 | 1.014 | | 5.6% | 12.6% | 275.1 | 1.014 | | 5.6% | 12.6% |
| December | 275.1 | 0.5618 | 252.9 | 0.7089 | | 8.1% | 26.2% | 252.9 | 0.7087 | | 8.1% | 26.1% |
| | | | | | Average | 6.4% | 19.8% | | | Average | 6.4% | 19.8% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 95.78 | 0.5125 | 31.94 | 1.086 | | 66.7% | 111.9% | 1.148 | 2.886 | | 98.8% | 463.1% |
| 3-day minimum | 99.21 | 0.507 | 33.78 | 1.054 | | 66.0% | 107.9% | 1.864 | 2.479 | | 98.1% | 389.0% |
| 7-day minimum | 103.6 | 0.4914 | 38.46 | 0.9652 | | 62.9% | 96.4% | 3.376 | 2.274 | | 96.7% | 362.8% |
| 30-day minimum | 119.8 | 0.4467 | 73.67 | 0.7839 | | 38.5% | 75.5% | 36.96 | 1.076 | | 69.1% | 140.9% |
| 90-day minimum | 160.6 | 0.4566 | 137.6 | 0.7121 | | 14.3% | 56.0% | 127.7 | 0.7427 | | 20.5% | 62.7% |
| 1-day maximum | 6512 | 1.307 | 3233 | 1.021 | | 50.4% | 21.9% | 4715 | 0.9742 | | 27.6% | 25.5% |
| 3-day maximum | 4873 | 1.225 | 2957 | 1.018 | | 39.3% | 16.9% | 4090 | 0.9675 | | 16.1% | 21.0% |
| 7-day maximum | 2932 | 1.083 | 2372 | 0.964 | | 19.1% | 11.0% | 2941 | 0.9363 | | 0.3% | 13.5% |
| 30-day maximum | 1077 | 0.9371 | 1096 | 0.9192 | | 1.8% | 1.9% | 1172 | 0.8798 | | 8.8% | 6.1% |
| 90-day maximum | 652.1 | 0.8277 | 670.3 | 0.8346 | | 2.8% | 0.8% | 692.7 | 0.8327 | | 6.2% | 0.6% |
| | | | | | Average | 36.2% | 50.0% | | | Average | 44.2% | 148.5% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 2 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 205.1 | 0.2227 | 211.8 | 0.2752 | | 3.3% | 23.6% | 79.37 | 0.2453 | | 61.3% | 10.1% |
| Date of maximum | 184 | 0.2285 | 177.9 | 0.2683 | | 3.3% | 17.4% | 180.6 | 0.2851 | | 1.8% | 24.8% |
| | | | | | Average | 3.3% | 20.5% | | | Average | 31.6% | 17.5% |
| | | | | | Score | 0 | 0 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 7.407 | 1.062 | 4.963 | 0.6764 | | 33.0% | 36.3% | 9.407 | 0.4224 | | 27.0% | 60.2% |
| Low pulse duration | 10.26 | 0.7058 | 15.91 | 0.8606 | | 55.1% | 21.9% | 8.534 | 0.5786 | | 16.8% | 18.0% |
| High pulse count | 4 | 0.7783 | 2.815 | 0.9453 | | 29.6% | 21.5% | 4.296 | 0.8705 | | 7.4% | 11.8% |
| High pulse duration | 2.95 | 0.7193 | 6.16 | 0.4557 | | 108.8% | 36.6% | 4.379 | 0.4425 | | 48.4% | 38.5% |
| | | | | | Average | 56.6% | 29.1% | | | Average | 24.9% | 32.1% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 184.9 | 0.8854 | 113 | 0.8866 | | 38.9% | 0.1% | 188.3 | 0.7739 | | 1.8% | 12.6% |
| Fall rate | -96.28 | -0.8028 | -39.12 | -0.8458 | | 59.4% | 5.4% | -83.34 | -0.7149 | | 13.4% | 10.9% |
| Number of reversals | 106.5 | 0.1648 | 56.78 | 0.2333 | | 46.7% | 41.6% | 64.26 | 0.2019 | | 39.7% | 22.5% |
| | | | | | Average | 48.3% | 15.7% | | | Average | 18.3% | 15.4% |
| | | | | | Score | 2 | 0 | | | Score | 0 | 0 |

| | DCFM | DCFD |
|---|---|---|
| Total Point | 6 | 7 |
| Classification | 3 | 3 |
| note: | Moderate risk of impact | Moderate risk of impact |

# Table 6.55 Evaluation Sheet by DHRAM Method for Control Point CP35

Control Point: CP35 Period: 1934-1960

| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 67.37 | 1.295 | 67.42 | 1.293 | | 0.1% | 0.2% | 67.42 | 1.293 | | 0.1% | 0.2% |
| February | 82.28 | 2.1 | 82.35 | 2.098 | | 0.1% | 0.1% | 82.35 | 2.098 | | 0.1% | 0.1% |
| March | 53.36 | 0.9074 | 53.47 | 0.9045 | | 0.2% | 0.3% | 53.48 | 0.9045 | | 0.2% | 0.3% |
| April | 189.7 | 1.538 | 189.8 | 1.536 | | 0.1% | 0.1% | 189.8 | 1.536 | | 0.1% | 0.1% |
| May | 215.8 | 1.377 | 216 | 1.375 | | 0.1% | 0.1% | 216 | 1.375 | | 0.1% | 0.1% |
| June | 186.3 | 1.671 | 186.6 | 1.668 | | 0.2% | 0.2% | 186.6 | 1.668 | | 0.2% | 0.2% |
| July | 120.7 | 2.498 | 120.8 | 2.493 | | 0.1% | 0.2% | 120.8 | 2.493 | | 0.1% | 0.2% |
| August | 63.4 | 2.716 | 63.63 | 2.705 | | 0.4% | 0.4% | 63.64 | 2.705 | | 0.4% | 0.4% |
| September | 184.5 | 1.889 | 184.6 | 1.887 | | 0.1% | 0.1% | 184.6 | 1.887 | | 0.1% | 0.1% |
| October | 124.4 | 1.566 | 124.5 | 1.565 | | 0.1% | 0.1% | 124.5 | 1.565 | | 0.1% | 0.1% |
| November | 62.61 | 1.748 | 62.63 | 1.747 | | 0.0% | 0.1% | 62.63 | 1.747 | | 0.0% | 0.1% |
| December | 76.22 | 1.488 | 76.24 | 1.487 | | 0.0% | 0.1% | 76.25 | 1.487 | | 0.0% | 0.1% |
| | | | | | Average | 0.1% | 0.2% | | | Average | 0.1% | 0.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 9.556 | 0.5235 | 1.491 | 1.043 | | 84.4% | 99.2% | 0 | 0 | | 100.0% | 100.0% |
| 3-day minimum | 9.84 | 0.5131 | 1.644 | 1.017 | | 83.3% | 98.2% | 0 | 0 | | 100.0% | 100.0% |
| 7-day minimum | 10.31 | 0.4764 | 2.207 | 0.8931 | | 78.6% | 87.5% | 0.005291 | 5.196 | | 99.9% | 990.7% |
| 30-day minimum | 12.01 | 0.4835 | 7.248 | 0.5655 | | 39.7% | 17.0% | 3.59 | 1.198 | | 70.1% | 147.8% |
| 90-day minimum | 19.92 | 0.5905 | 21.49 | 0.6273 | | 7.9% | 6.2% | 19.77 | 0.724 | | 0.8% | 22.6% |
| 1-day maximum | 6658 | 0.8417 | 2596 | 0.9676 | | 61.0% | 15.0% | 3549 | 0.9052 | | 46.7% | 7.5% |
| 3-day maximum | 3868 | 0.8548 | 2211 | 0.9827 | | 42.8% | 15.0% | 2873 | 0.9148 | | 25.7% | 7.0% |
| 7-day maximum | 2099 | 0.7933 | 1527 | 0.864 | | 27.3% | 8.9% | 1844 | 0.8061 | | 12.1% | 1.6% |
| 30-day maximum | 631.5 | 0.7991 | 607.6 | 0.7907 | | 3.8% | 1.1% | 631.7 | 0.7728 | | 0.0% | 3.3% |
| 90-day maximum | 315.1 | 0.8857 | 310.1 | 0.8842 | | 1.6% | 0.2% | 316.9 | 0.8782 | | 0.6% | 0.8% |
| | | | | | Average | 43.0% | 34.8% | | | Average | 45.6% | 138.1% |
| | | | | | Score | 1 | 1 | | | Score | 2 | 2 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 212.8 | 0.1583 | 192.4 | 0.2563 | | 9.6% | 61.9% | 43.96 | 0.134 | | 79.3% | 15.4% |
| Date of maximum | 181.3 | 0.1916 | 175.4 | 0.2433 | | 3.3% | 27.0% | 176.6 | 0.2369 | | 2.6% | 23.6% |
| | | | | | Average | 6.4% | 44.4% | | | Average | 41.0% | 19.5% |
| | | | | | Score | 0 | 1 | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 6.333 | 0.9792 | 9.407 | 0.4366 | | 48.5% | 55.4% | 11.37 | 0.3228 | | 79.5% | 67.0% |
| Low pulse duration | 12.16 | 0.5765 | 9.611 | 0.3454 | | 21.0% | 40.1% | 7.434 | 0.2257 | | 38.9% | 60.8% |
| High pulse count | 4.296 | 0.7298 | 2.741 | 0.8681 | | 36.2% | 19.0% | 2.963 | 0.8293 | | 31.0% | 13.6% |
| High pulse duration | 1.976 | 0.4097 | 6.047 | 0.6312 | | 206.0% | 54.1% | 4.604 | 0.4146 | | 133.0% | 1.2% |
| | | | | | Average | 77.9% | 42.1% | | | Average | 70.6% | 35.7% |
| | | | | | Score | 3 | 1 | | | Score | 3 | 1 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 266 | 0.8631 | 79.62 | 0.8872 | | 70.1% | 2.8% | 121.4 | 0.7779 | | 54.4% | 9.9% |
| Fall rate | -109.1 | -0.7646 | -23.5 | -0.8918 | | 78.5% | 16.6% | -43.93 | -0.7715 | | 59.7% | 0.9% |
| Number of reversals | 80.96 | 0.1669 | 70.07 | 0.1513 | | 13.5% | 9.3% | 71.52 | 0.1203 | | 11.7% | 27.9% |
| | | | | | Average | 54.0% | 9.6% | | | Average | 41.9% | 12.9% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 0 |

| | | | |
|---|---|---|---|
| Total Point | 9 | Total Point | 10 |
| Classification | 3 | Classification | 3 |
| note: | Moderate risk of impact | note: | Moderate risk of impact |

Both MDNF and DDNF have underestimated minimum flows, and have different durations of low and high pulses than the USGS flows at the control points CP35 as tabulated in Table 6.56. These are also attributed to the influence of the return flows from ground water uses within the basin.

Table 6.56 Evaluation Sheet by DHRAM Method for Control Point CP37

| Control Point: | CP37 | Period: | 1939-1960 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IHA statistics group | USGS | | DCFM | | | Absolute Chages | | DCFD | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | | | | | | |
| January | 374.9 | 0.9253 | 359.9 | 1.102 | | 4.0% | 19.1% | 372.9 | 1.072 | | 0.5% | 15.9% |
| February | 469 | 1.253 | 470.4 | 1.404 | | 0.3% | 12.1% | 483.3 | 1.366 | | 3.0% | 9.0% |
| March | 332.8 | 0.5539 | 338.1 | 0.757 | | 1.6% | 36.7% | 338.1 | 0.757 | | 1.6% | 36.7% |
| April | 601.1 | 1.115 | 635.2 | 1.198 | | 5.7% | 7.4% | 635.2 | 1.198 | | 5.7% | 7.4% |
| May | 885.4 | 1.065 | 933.3 | 1.126 | | 5.4% | 5.7% | 933.3 | 1.126 | | 5.4% | 5.7% |
| June | 598.2 | 0.9392 | 626.4 | 0.9546 | | 4.7% | 1.6% | 626.4 | 0.9545 | | 4.7% | 1.6% |
| July | 535.5 | 1.637 | 511.9 | 1.721 | | 4.4% | 5.1% | 511.9 | 1.721 | | 4.4% | 5.1% |
| August | 300 | 0.6999 | 271.8 | 0.8438 | | 9.4% | 20.6% | 271.8 | 0.8437 | | 9.4% | 20.5% |
| September | 992.1 | 1.413 | 969.8 | 1.469 | | 2.2% | 4.0% | 969.8 | 1.469 | | 2.2% | 4.0% |
| October | 815.5 | 1.523 | 811.1 | 1.557 | | 0.5% | 2.2% | 811.1 | 1.557 | | 0.5% | 2.2% |
| November | 547.1 | 1.187 | 517.4 | 1.284 | | 5.4% | 8.2% | 517.4 | 1.284 | | 5.4% | 8.2% |
| December | 388 | 0.8919 | 362.3 | 1.049 | | 6.6% | 17.6% | 362.3 | 1.049 | | 6.6% | 17.6% |
| | | | | | Average | 4.2% | 11.7% | | | Average | 4.1% | 11.2% |
| | | | | | Score | 0 | 0 | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | | | | | | |
| 1-day minimum | 120.2 | 0.5493 | 49 | 0.7918 | | 59.2% | 44.1% | 3.182 | 3.51 | | 97.4% | 539.0% |
| 3-day minimum | 122.8 | 0.5434 | 51.64 | 0.7752 | | 57.9% | 42.7% | 3.621 | 3.527 | | 97.1% | 549.1% |
| 7-day minimum | 127.3 | 0.536 | 57.8 | 0.7425 | | 54.6% | 38.5% | 5.981 | 2.832 | | 95.3% | 428.4% |
| 30-day minimum | 147.1 | 0.4955 | 104.2 | 0.665 | | 29.2% | 34.2% | 56.22 | 1.256 | | 61.8% | 153.5% |
| 90-day minimum | 210.6 | 0.5333 | 185.3 | 0.651 | | 12.0% | 22.1% | 173.2 | 0.7436 | | 17.8% | 39.4% |
| 1-day maximum | 10140 | 0.8336 | 6040 | 0.908 | | 40.4% | 8.9% | 8116 | 0.9082 | | 20.0% | 8.9% |
| 3-day maximum | 8537 | 0.857 | 5296 | 0.8863 | | 38.0% | 3.4% | 7006 | 0.8818 | | 17.9% | 2.9% |
| 7-day maximum | 5875 | 0.8394 | 4334 | 0.8795 | | 26.2% | 4.8% | 5551 | 0.8337 | | 5.5% | 0.7% |
| 30-day maximum | 2137 | 0.8196 | 2166 | 0.8381 | | 1.4% | 2.3% | 2327 | 0.8371 | | 8.9% | 2.1% |
| 90-day maximum | 1218 | 0.8486 | 1236 | 0.853 | | 1.5% | 0.5% | 1280 | 0.8347 | | 5.1% | 1.6% |
| | | | | | Average | 32.0% | 20.2% | | | Average | 42.7% | 172.6% |
| | | | | | Score | 1 | 0 | | | Score | 1 | 3 |
| Parameter Group #3 | | | | | | | | | | | | |
| Date of minimum | 218.3 | 0.1787 | 209.6 | 0.2618 | | 4.0% | 46.5% | 81.18 | 0.2653 | | 62.8% | 48.5% |
| Date of maximum | 183.3 | 0.1899 | 197.7 | 0.2202 | | 7.9% | 16.0% | 208.6 | 0.2679 | | 13.8% | 41.1% |
| | | | | | Average | 5.9% | 31.2% | | | Average | 38.3% | 44.8% |
| | | | | | Score | 0 | 1 | | | Score | 1 | 1 |
| Parameter Group #4 | | | | | | | | | | | | |
| Low pulse count | 6.318 | 1.057 | 4.409 | 0.659 | | 30.2% | 37.7% | 7.364 | 0.5056 | | 16.6% | 52.2% |
| Low pulse duration | 13.94 | 0.4568 | 17.36 | 0.6526 | | 24.5% | 42.9% | 11.51 | 0.4545 | | 17.4% | 0.5% |
| High pulse count | 4.091 | 0.948 | 2.227 | 1.082 | | 45.6% | 14.1% | 3.227 | 0.8496 | | 21.1% | 10.4% |
| High pulse duration | 3.37 | 0.3921 | 9.942 | 0.7695 | | 195.0% | 96.3% | 5.81 | 0.4433 | | 72.4% | 13.1% |
| | | | | | Average | 73.8% | 47.7% | | | Average | 31.9% | 19.0% |
| | | | | | Score | 3 | 1 | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | | | | | | |
| Rise rate | 318.7 | 0.8789 | 130.2 | 0.929 | | 59.1% | 5.7% | 210.4 | 0.7697 | | 34.0% | 12.4% |
| Fall rate | -166.4 | -0.8241 | -59.52 | -0.8701 | | 64.2% | 5.6% | -116.9 | -0.7226 | | 29.7% | 12.3% |
| Number of reversals | 105.2 | 0.1729 | 42.41 | 0.1562 | | 59.7% | 9.7% | 48.45 | 0.1577 | | 53.9% | 8.8% |
| | | | | | Average | 61.0% | 7.0% | | | Average | 39.2% | 11.2% |
| | | | | | Score | 2 | 0 | | | Score | 1 | 0 |
| | | | | | | | | | | | | |
| | | | Total Point | | | 8 | | | Total Point | | 8 | |
| | | | Classification | | | 3 | | | Classification | | 3 | |
| | | | note: | | Moderate risk of impact | | | | note: | Moderate risk of impact | | |

Table 6.57 summarizes the comparative scores, made through the qualitative comparison of both annual median flow duration curves at 12 control points. Annual flow duration curves of each flow at all the 12 control points as shown in Figures 6.17 to 6.28, respectively.

Table 6.57 Comparative Evaluation of Annual Median Flow Duration Curve for the GSA WAM

| CP | Data Period | Comparative Score | |
|---|---|---|---|
| | | USGS vs. MDNF | USGS vs. DDNF |
| Total | | 19 | 5 |
| CP01 | 06/01/1939-12/31/1960 | 2 | 0 |
| CP02 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP04 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP08 | 01/01/1934-12/31/1960 | 1 | 1 |
| CP10 | 05/01/1939-12/31/1960 | 2 | 0 |
| CP11 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP15 | 01/01/1934-12/31/1960 | 1 | 1 |
| CP18 | 03/01/1939-12/31/1960 | 1 | 1 |
| CP28 | 08/01/1939-12/31/1960 | 0 | 2 |
| CP32 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP35 | 01/01/1934-12/31/1960 | 2 | 0 |
| CP37 | 03/01/1939-12/31/1960 | 2 | 0 |

The annual median curves of MDNF are mostly more similar to the USGS flows than the DDNF except for the control points CP08, 15, 18, and 28. Both annual median curves are closely similar to the USGS flows at the control points CP08 and CP15. The DDNF has more similar annual median curve to the USGS flows than the MDNF at only the control point CP28. At the control point CP18, both annual median curves of MDNF and DDNF are totally different from the USGS flows. Therefore, comparative evaluation is impossible at this control point. 1 point is given to both the disaggregated daily flows, respectively.

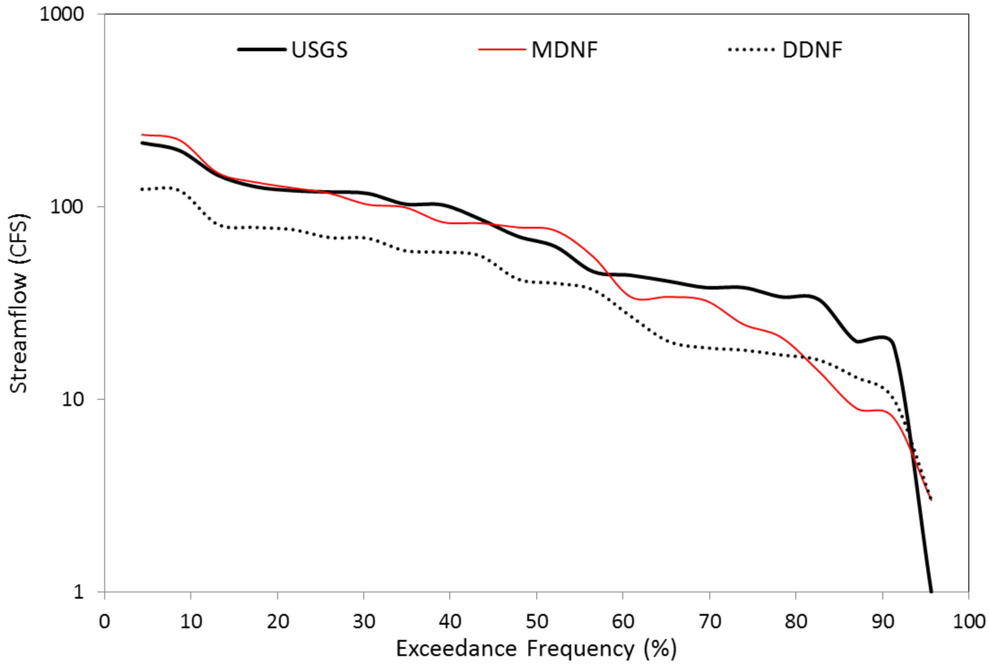



Figure 6.17 Annual Median Flow Duration Curves at CP01

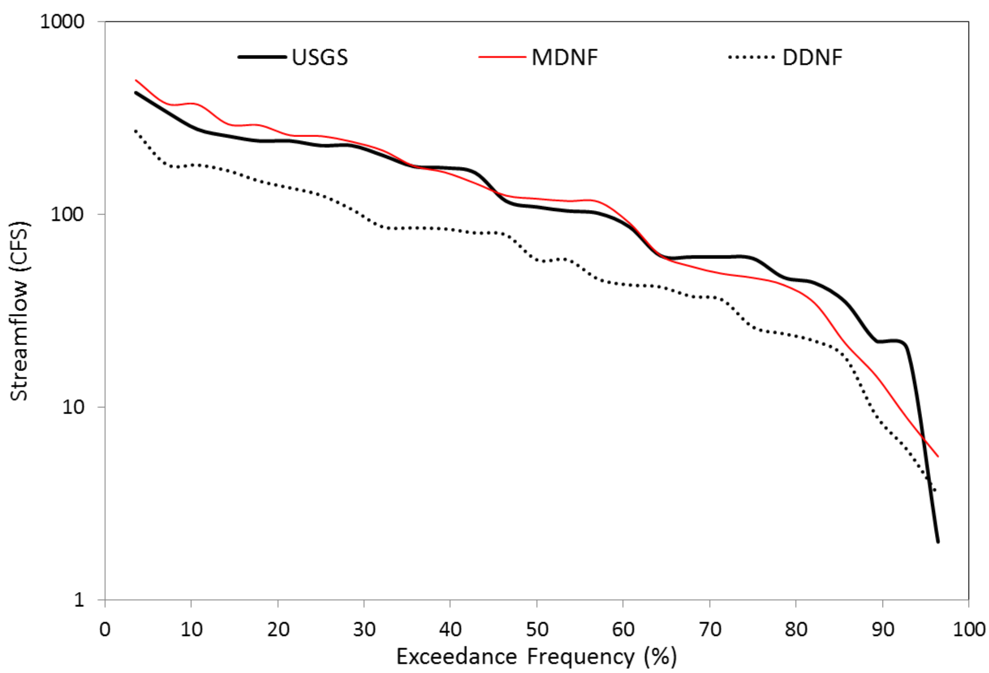



Figure 6.18 Annual Median Flow Duration Curves at CP02

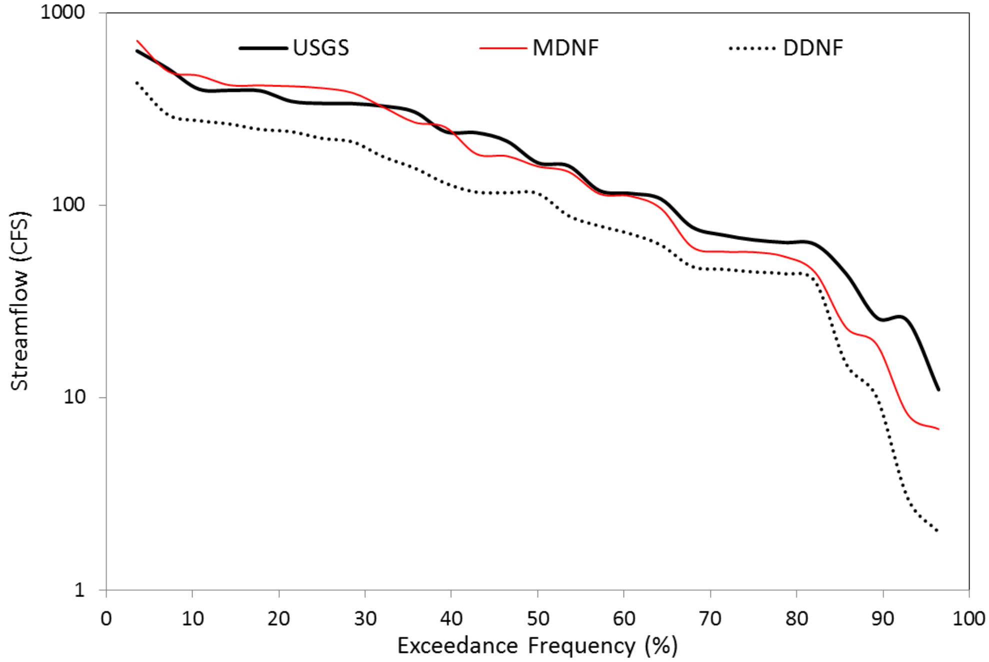



Figure 6.19 Annual Median Flow Duration Curves at CP04

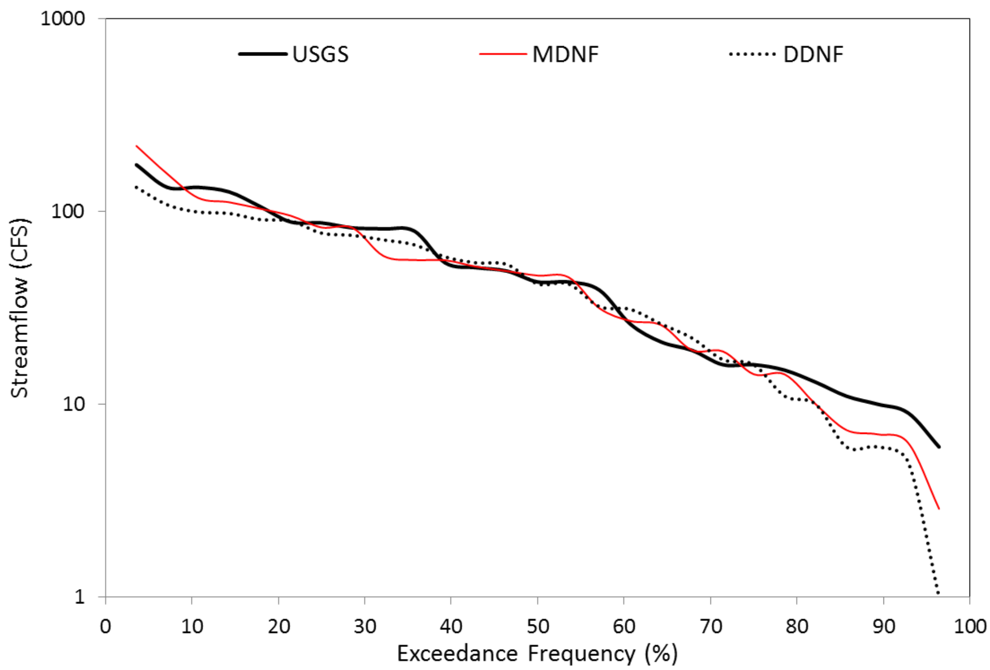



Figure 6.20 Annual Median Flow Duration Curves at CP08

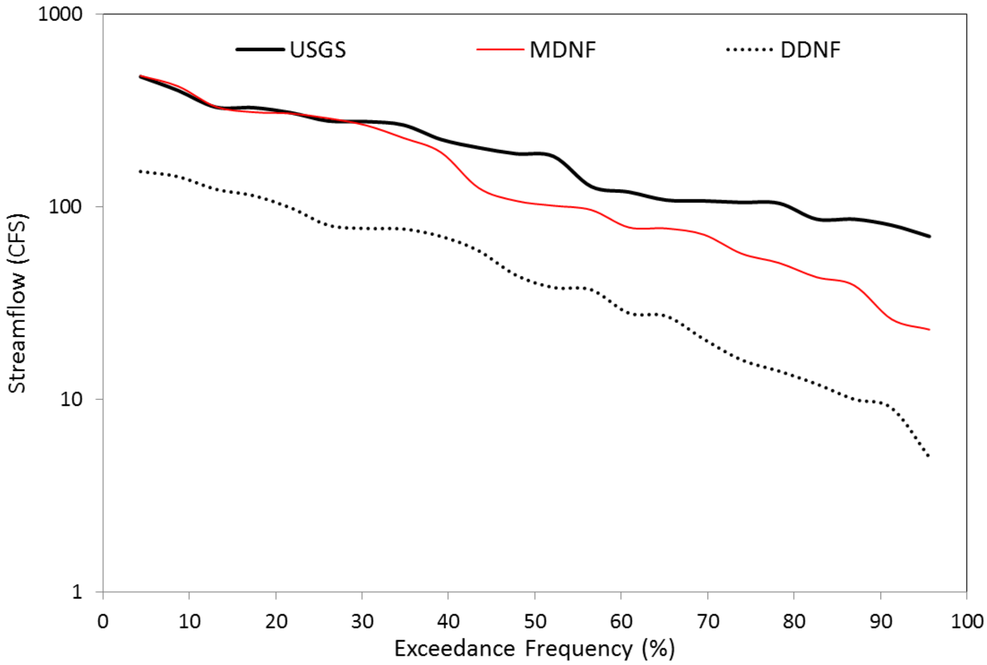



Figure 6.21 Annual Median Flow Duration Curves at CP10

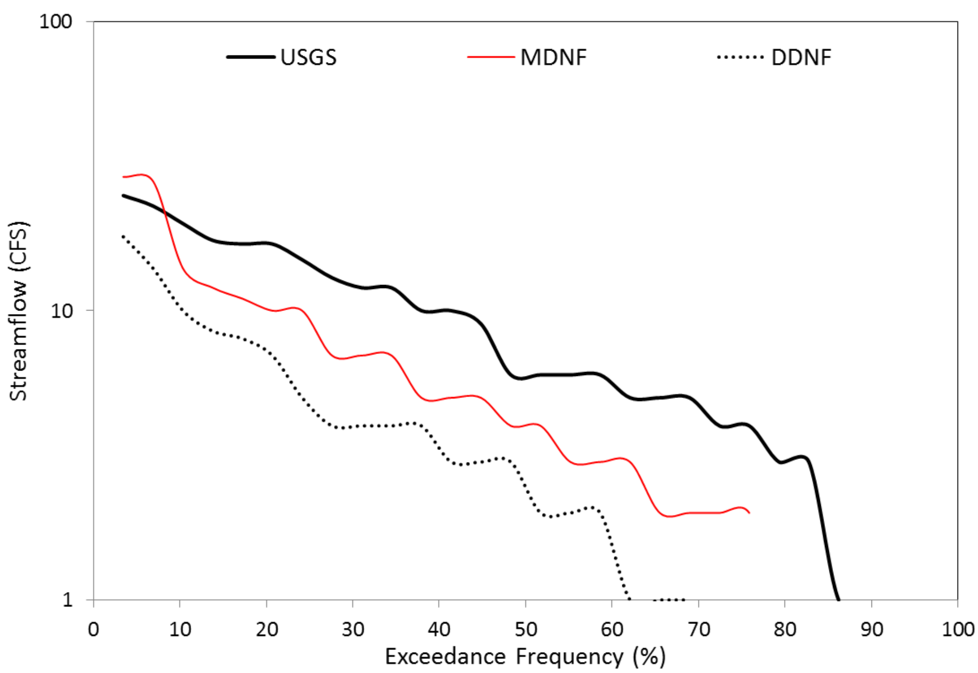



Figure 6.22 Annual Median Flow Duration Curves at CP11

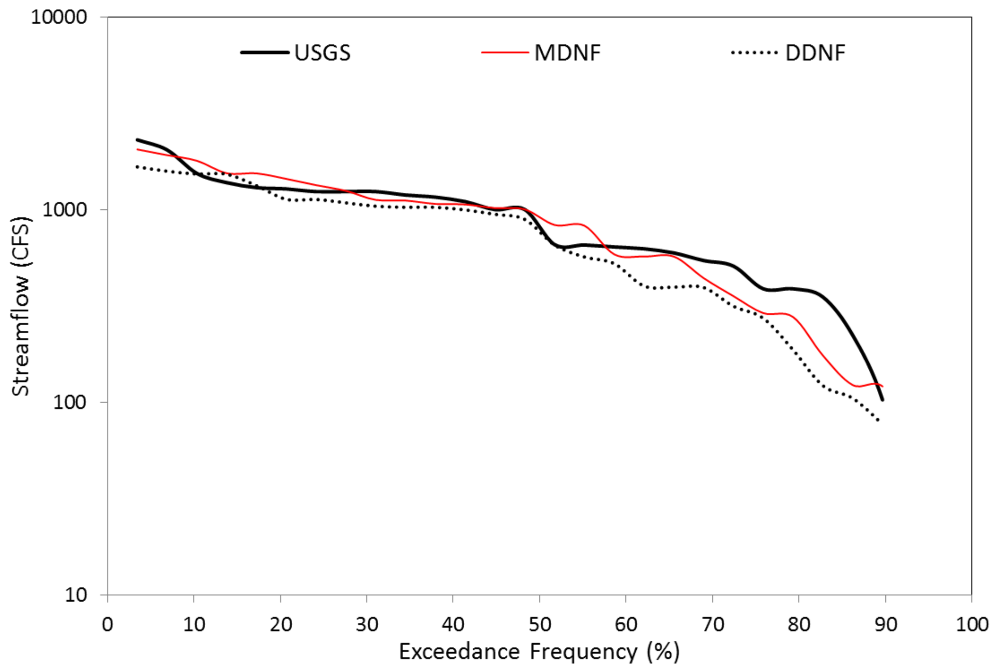



Figure 6.23 Annual Median Flow Duration Curves at CP15

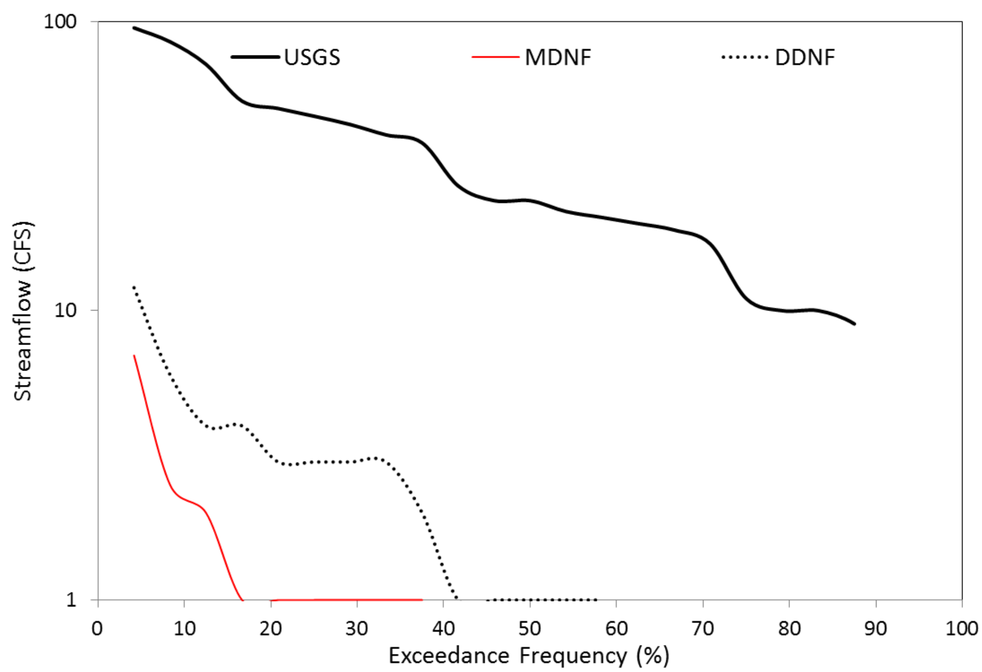



Figure 6.24 Annual Median Flow Duration Curves at CP18

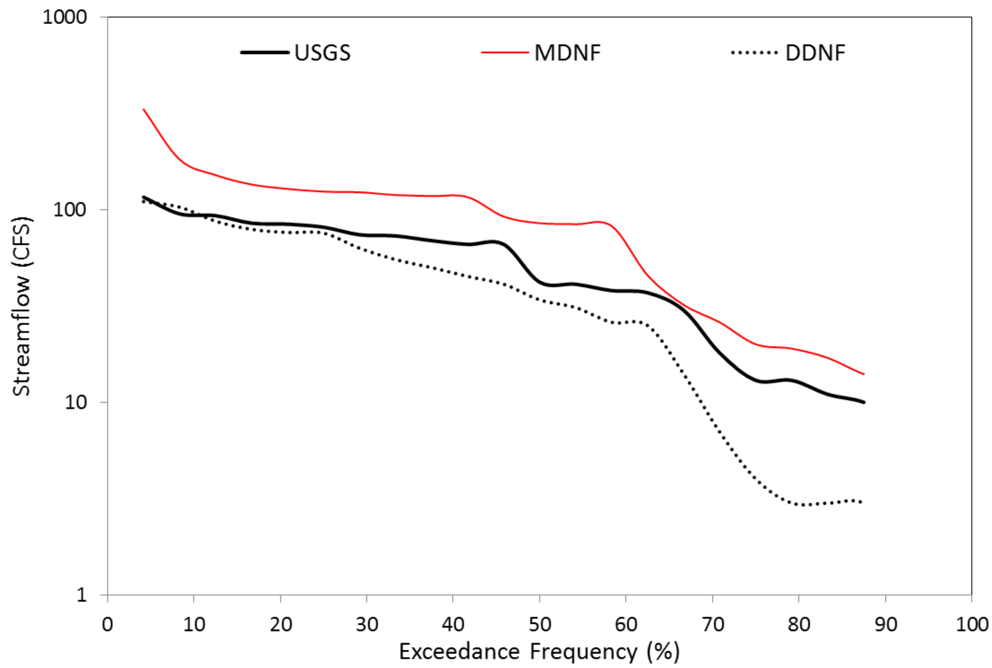



Figure 6.25 Annual Median Flow Duration Curves at CP28

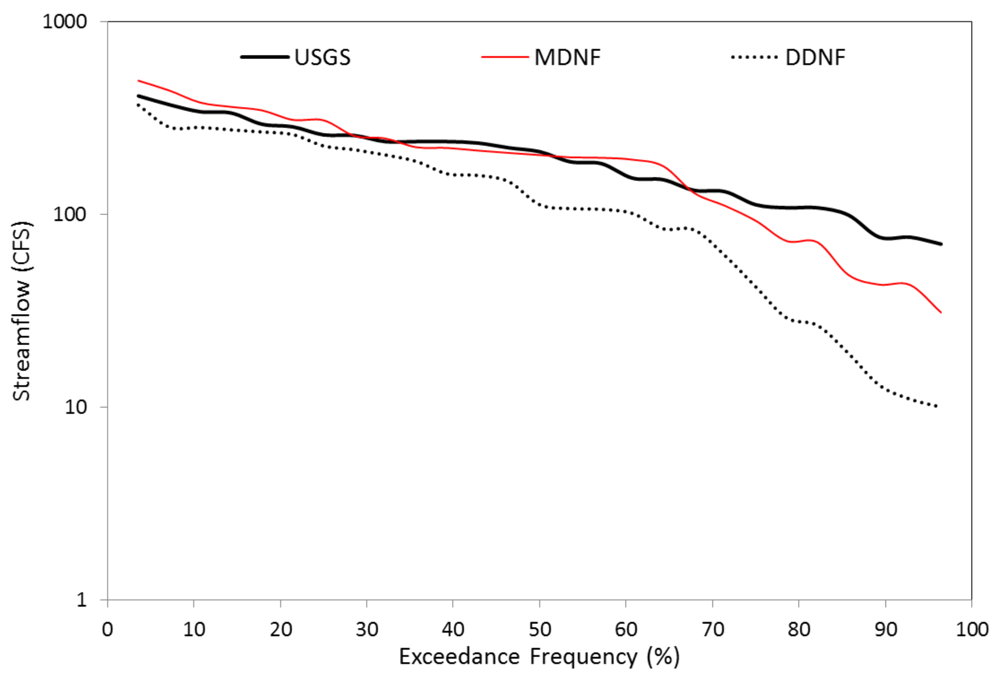



Figure 6.26 Annual Median Flow Duration Curves at CP32

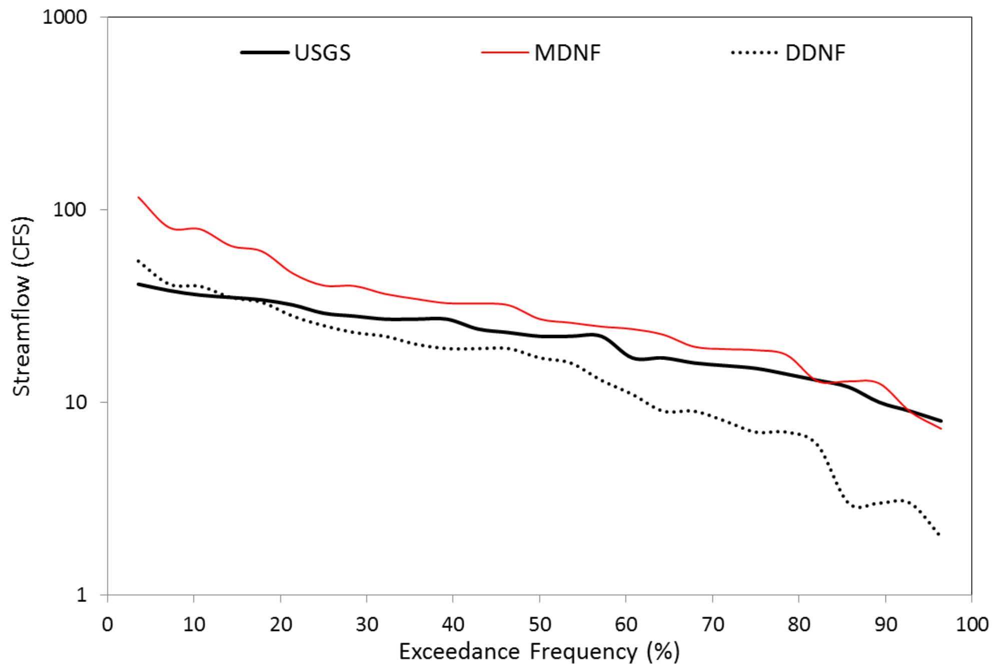



Figure 6.27 Annual Median Flow Duration Curves at CP35

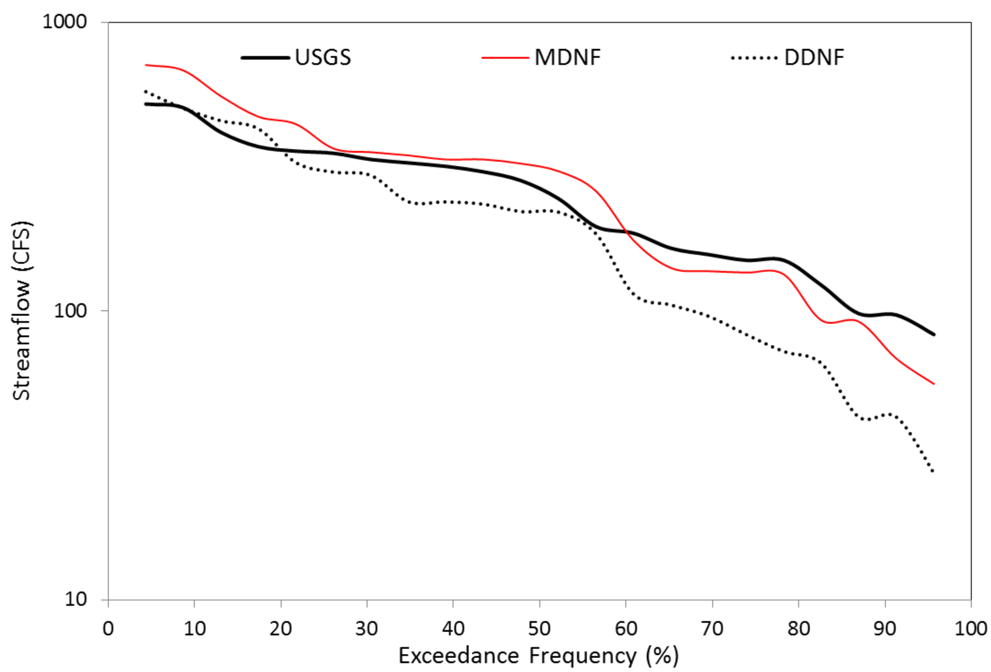



Figure 6.28 Annual Median Flow Duration Curves at CP37

The total scores for both the disaggregated flows are tabulated in Table 6.58. MDNF has better performances than DDNF on all evaluation methods. Both the disaggregated flows would have slightly different flow regimes from the USGS daily recorded flows at some control points. These are attributed to the reasons that various human impacts, such as dam operations and effluent from spring water sources influenced on USGS daily recorded flows for periods-of-comparison. However, the total score of the comparative evaluation indicates that MDNF has relatively more similar naturalized flow regimes than DDNF.

Accordingly, the calibration strategy with monthly naturalized flows from the WAM datasets for the daily SWAT is selected for the daily GSA WAM as tabulated in Table 6.58.

Table 6.58 Selection of Calibration Strategy for the GSA WAM

| Methods | Evaluation purposes | Calibration Strategy | |
|---|---|---|---|
| | | Monthly WAM datasets | Daily USGS recorded data |
| Total Score | | 8 | 0 |
| Statistic Evaluation (NSE) | Streamflow timing | 2 | 0 |
| Flow Frequency Metric | Streamflow regime | 2 | 0 |
| DHRAM (IHA) | Hydrologic characteristics alteration | 2 | 0 |
| Median Annual Flow Duration Curve | Overall hydrologic state of a river | 2 | 0 |

# CHAPTER VII
# MODELING SB3 ENVIRONMENTAL FLOW STANDARDS

The process created by the 1997 Senate Bill 3 (SB3) for establishing environmental flow requirements is explained in detail by Wurbs and Hoffpauir (2013b) and briefly described in Chapters 1 and 2 of this dissertation. SB3 standards have been established for the case study river basins at the USGS gauging stations noted in this chapter. These standards have been incorporated in the Sabine, Neches, and GSA WAMs as described in this chapter. Simulation results from the daily WAMs are summarized in the present Chapter VII from the perspective of analyzing the SB3 environmental flow requirements. Further statistical analyses of flows are presented in Chapter VIII.

## 7.1 Senate Bill 3 Environmental Flow Standards for the Basins

### 7.1.1 Sabine River Basin

The Recommendation Report for the Sabine and Neches Rivers was submitted by the Bay and Basin Expert Science Team (BBEST) to the Basin and Bay Area Stakeholder Committee (BBASC) and TCEQ in November 2009. The TCEQ received the Recommendation Report from the Bay and Basin Area Stakeholder Committee (BBASC) in May 2010. The TCEQ finalized the standards for the Sabine and Neches Rivers effective May 15, 2011.

The environmental flow standards for surface water for the Sabine and Neches Rivers are published in Texas Administrative Code Title 30, Part 1, Chapter 298, Subchapter C. The Code includes environmental flow standards at ten USGS gaging stations, five sites in the Sabine River Basin and five sites in the Neches River Basin. The Sabine WAM four primary and one secondary control points corresponding to the five USGS gage sites are listed with descriptive information in Table 6.2. New adjacent control points BSBSE, SRGWE, SRBEE, 29500E, and SRRLE for the environmental flow standards were added to the daily WAM (Wurbs *et al.*, 2014a).

The environmental flow standards include seasonal subsistence flows, base flows, and high flow pulses depending on four seasons, listed in Table 7.1.

Table 7.1 Months Included in Each Season for the Sabine River Basin

| Season | Months |
|---|---|
| Winter | January, February, March |
| Spring | April, May, June |
| Summer | July, August, September |
| Fall | October, November, December |

*Subsistence and base flow standards*

Table 7.2 tabulates the subsistence flow standards for the four control points in the Sabine River Basin. If the flow at a control point is less than the applicable subsistence flow standard, then water right holders may not make diversions from the river (Wurbs *et al.*, 2014a). If the flow is greater than the subsistence flow standard and less than the applicable base flow standard, water right holders may make diversions as long as the flow does not drop below the subsistence flow (Wurbs *et al.*, 2014a). Table 7.3 tabulates base flow standards. If the flow at a control point is greater than the applicable base flow standard and less than the applicable pulse flow trigger level, then water right holders may make diversions as long as the flow does not drop below the base flow standard (Wurbs *et al.*, 2014a).

Table 7.2 Subsistence Flow Standards (cfs)
for the Sabine River Basin

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| BSBSE | 20 | 9 | 8 | 8 |
| SRGWE | 45 | 22 | 14 | 17 |
| SRBEE | 66 | 28 | 22 | 22 |
| 29500E | 28 | 20 | 20 | 20 |
| SRRLE | 949 | 436 | 396 | 396 |

Table 7.3 Base Flow Standards (cfs) for the Sabine River Basin

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| BSBSE | 73 | 33 | 15 | 22 |
| SRGWE | 305 | 131 | 37 | 54 |
| SRBEE | 482 | 255 | 56 | 83 |
| 29500E | 62 | 42 | 31 | 40 |
| SRRLE | 1672 | 1329 | 737 | 809 |

*High flow pulse standards*

The high flow pulse standards are activated when flow at a control point goes beyond the applicable high flow pulse trigger level. Water right holders may not be allowed to divert water until either the applicable volume or duration time has passed since engagement of the trigger flow level. However, diversions can be allowed before the volume or duration criteria are satisfied if the flow at the control point goes beyond the high flow pulse trigger level, as long as diversions do not lead to the flow to go below the high flow pulse trigger level. Winter and Summer seasons have one pulse per season, and Spring and Fall seasons have two pulses per season for all five control points according to the criteria specified in Table 7.4. The tracking of high flow pulse events each season is performed independently of preceding and subsequent seasons (Wurbs *et al.*, 2014a).

*Water right permit conditions*

The environmental flow standards will be differently applied for some water right permits issued after the effective date of the environmental flow standards depending on the conditions of the new permit. Specifically, water right permits with an authorization to divert 10,000 acre-feet or less per year are not required to protect the high flow pulse requirements (Wurbs *et al.*, 2014a). However, as discussed later in this chapter, the input records corresponding to the SB-3 requirements in the Sabine WAM DAT file were not configured to allow junior water right exemptions from honoring downstream senior instream flow requirements (Wurbs *et al.*, 2014a).

Table 7.4 High Flow Pulse Standards for the Sabine River Basin

| WAM CP | Criteria | Winter | Spring | Summer | Fall |
|---|---|---|---|---|---|
| BSBSE | Trigger (cfs) | 358 | 313 | 50 | 130 |
| | Volume (ac-ft) | 5,932 | 5,062 | 671 | 2,189 |
| | Duration (days) | 10 | 13 | 6 | 9 |
| SRGWE | Trigger (cfs) | 1,880 | 1,580 | 168 | 380 |
| | Volume (ac-ft) | 48,599 | 51,150 | 2,752 | 1098 |
| | Duration (days) | 15 | 16 | 7 | 11 |
| SRBEE | Trigger (cfs): | 2,900 | 2,160 | 285 | 628 |
| | Volume (ac-ft) | 84,998 | 72,092 | 5,436 | 7,245 |
| | Duration (days) | 15 | 15 | 6 | 9 |
| 29500E | Trigger (cfs) | 693 | 350 | 109 | 322 |
| | Volume (ac-ft) | 4,911 | 2,545 | 873 | 2,232 |
| | Duration (days) | 8 | 7 | 5 | 7 |
| SRRLE | Trigger (cfs) | 1,600 | 3,250 | 3,380 | 2020 |
| | Volume (ac-ft) | 10,202 | 42,883 | 54,321 | 17,662 |
| | Duration (days) | 3 | 8 | 11 | 5 |

### 7.1.2 Neches River Basin

The environmental flow standards for surface water for the Sabine and Neches Rivers are provided in Texas Administrative Code Title 30, Part 1, Chapter 298, Subchapter C. Environmental flow standards are established at five USGS gaging stations in the Neches River Basin. Instream flow standards at the five Neches River Basin locations were incorporated into the daily Neches WAM using the modeling techniques (Wurbs *et al.*, 2014b). The Neches WAM primary control points corresponding to the five USGS gage sites are listed with descriptive information in Table 6.3.

Although not necessary, five new control points were added immediately downstream of the primary control points dedicated solely to the SB3 standards (Wurbs *et al.*, 2014b). The identifiers of the new control points are the same as original control points, with the letter E added to the end (Wurbs *et al.*, 2014b). The instream flow standards are established dividing into seasonal subsistence flows, base flows, and high flow pulses. Table 7.5 defines four seasons according to the months.

Table 7.5 Months Included in Each Season for the Neches River Basin

| Season | Months |
|---|---|
| Winter | January, February, March |
| Spring | April, May, June |
| Summer | July, August, September |
| Fall | October, November, December |

Table 7.6 tabulates the subsistence flow standards for the four control points in the Neches River Basin.

Table 7.6 Subsistence Flow Standards (cfs) for the Neches River Basin

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| NENEE | 51 | 21 | 12 | 13 |
| NEROE | 67 | 29 | 21 | 21 |
| ANALE | 55 | 18 | 11 | 16 |
| NEEVE | 228 | 266 | 228 | 228 |
| VIKOE | 83 | 49 | 41 | 41 |

Table 7.7 also defines the base flow standards, and Table 7.8 specifies high flow pulse standards depending on four seasons for the Neches River Basins.

Table 7.7 Base Flow Standards (cfs) for the Neches River Basin

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| NENEE | 196 | 96 | 46 | 80 |
| NEROE | 603 | 420 | 67 | 90 |
| ANALE | 277 | 90 | 40 | 52 |
| NEEVE | 1,925 | 1,804 | 580 | 512 |
| VIKOE | 264 | 117 | 77 | 98 |

Table 7.8 High Flow Pulse Standards for the Neches River Basin

| WAM CP ID | Criteria | Winter | Spring | Summer | Fall |
|---|---|---|---|---|---|
| NENEE | Trigger (cfs): | 833 | 820 | 113 | 345 |
| | Volume (ac-ft): | 19,104 | 20,405 | 1,339 | 5,391 |
| | Duration (days): | 10 | 12 | 4 | 8 |
| NEROE | Trigger (cfs): | 3,080 | 1,720 | 195 | 515 |
| | Volume (ac-ft): | 82,195 | 39,935 | 1,548 | 8,172 |
| | Duration (days): | 14 | 12 | 5 | 8 |
| ANALE | Trigger (cfs): | 1,620 | 1,100 | 146 | 588 |
| | Volume (ac-ft): | 37,114 | 24,117 | 2,632 | 12,038 |
| | Duration (days): | 13 | 14 | 8 | 12 |
| NEEVE | Trigger (cfs): | 2,020 | 3,830 | 1,540 | 1,570 |
| | Volume (ac-ft): | 20,920 | 68,784 | 21,605 | 17,815 |
| | Duration (days): | 6 | 12 | 9 | 7 |
| VIKOE | Trigger (cfs): | 2,010 | 1,380 | 341 | 712 |
| | Volume (ac-ft): | 36,927 | 23,093 | 6,159 | 11,426 |
| | Duration (days): | 13 | 13 | 8 | 9 |

### 7.1.3 GSA River Basins

The Recommendation Report for the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays was submitted by The Bay and Basin Expert Science Team (BBEST) to the BBASC and TCEQ in March 2011. TCEQ received the Recommendation Report of The Bay and Basin Area Stakeholder Committee (BBASC) in September 2011 and a Work Plan in May 2012, respectively. TCEQ adopted environmental flow standards for the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays on effective August 30, 2012.

The environmental flow standards for surface water for the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays are documented in Texas Administrative Code Title 30, Part 1, Chapter 298, Subchapter E. GSA River Basins has flow standards at 16 control point locations, including 9 sites in the Guadalupe River Basin, 6 sites in the San Antonio River Basin, and 1 site in the Mission River Basin. Thus, the GSA WAM incorporate the flow standards for the 15 control points located in the Guadalupe and San Antonio River Basins. Table

6.5 lists the 15 control points with descriptive information. The priority date used for water availability modeling is March 1, 2011, the date the BBEST report was submitted (Wurbs *et al.*, 2014c).

The environmental flow standards have three different recommendations for subsistence flows, base flows, and high flow pulses. These are seasonally various and, in the San Antonio River Basin, according to hydrologic conditions. Each season includes three with the winter season beginning in January, as listed in Table 7.9.

Table 7.9 Months Included in Each Season for the GSA River Basins

| Season | Months |
|---|---|
| Winter | January, February, March |
| Spring | April, May, June |
| Summer | July, August, September |
| Fall | October, November, December |

In the San Antonio River Basin, three hydrologic conditions (dry, average, and wet) are decided depending on the amount of 12-month cumulative stream flows. The hydrologic conditions are evaluated once at the beginning of each season based on 12-month cumulative flows on the last day of the preceding season and applied for the entire season. Table 7.10 lists the cumulative stream flow limits for each hydrologic condition. These were determined by assessing the exceedance frequency curves for 12-month cumulative monthly naturalized flows from the GSA WAM, such that dry conditions occurred 25% of the time, average conditions occurred 50% of the time, and wet conditions occurred 25% of the time (Wurbs *et al.*, 2014c).

The cumulative stream flow limits were determined based on the existing naturalized flow values for standard period-of-analysis from 1934-1989. A separate set of cumulative stream flow limits was developed using the original naturalized flows for the period from 1934-1989 and *WRAP-HYD* extended naturalized flows for the period from 1990-2013 (Wurbs *et al.*, 2014c).

Table 7.10 12-Month Cumulative Naturalized Stream Flow Limits for Evaluating Hydrologic Conditions at Control Points in the San Antonio River Basin

| Control Point | Hydrologic Condition<br>Dry | <br>Average | <br>Wet |
|---|---|---|---|
| | Original 1934-1989 Dataset | | |
| P382411 | 26,591 | 26,591 - 103,345 | 103,345 |
| CP28 | 71,879 | 71,879 - 245,191 | 245,191 |
| CP29 | 111,543 | 111,543 - 379,920 | 379,920 |
| CP32 | 136,710 | 136,710 - 436,835 | 436,835 |
| CP35 | 30,622 | 30,622 - 119,904 | 119,904 |
| CP37 | 220,177 | 220,177 - 713,915 | 713,915 |
| | Original 1934-1989 and *WRAP-HYD* Extended 1990-2012 Dataset | | |
| P382411 | 29,845 | 29,845 – 108,419 | 108,419 |
| CP28 | 74,460 | 74,460 – 250,583 | 250,583 |
| CP29 | 121,364 | 121,364 – 402,324 | 402,324 |
| CP32 | 149,603 | 149,603 – 457,485 | 457,485 |
| CP35 | 35,672 | 35,672 – 132,946 | 132,946 |
| CP37 | 231,340 | 231,340 – 765,797 | 765,797 |

The subsistence flow standard is normally applied similarly in the two river basins. However, for control points located in the San Antonio River Basin, the subsistence flow standard is applicable during dry hydrologic conditions when measured stream flows fall below the subsistence flow level (Wurbs *et al.*, 2014c). Table 7.11 shows the subsistence flow levels vary seasonally.

In both basins, if the measured stream flow is above the subsistence flow level and below the base flow level, then junior water rights must pass the subsistence flow plus 50% of the difference between the measured stream flow and the subsistence flow (Wurbs *et al.*, 2014c). The based flow levels are seasonally various for the control points in the Guadalupe River Basin, as listed in Table 7.12, and the control points in the San Antonio River Basin have seasonally various the base flow levels and according to hydrologic conditions, as listed in Table 7.13.

Table 7.11 Subsistence Flow Standards (cfs) in the GSA River Basins

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| CP01E | 31 | 18 | 2 | 25 |
| CP02E | 18 | 18 | 18 | 18 |
| CP08E | 10 | 13 | 8 | 10 |
| CP10E | 89 | 89 | 73 | 81 |
| CP11E | 3 | 2 | 1 | 1 |
| C38461E | 210 | 210 | 210 | 180 |
| CP13E | 4 | 1 | 1 | 2 |
| CP14E | 130 | 120 | 130 | 86 |
| CP15E | 160 | 130 | 150 | 110 |
| P38241E | 6 | 7 | 1 | 2 |
| CP28E | 14 | 12 | 8 | 13 |
| CP29E | 60 | 60 | 60 | 60 |
| CP32E | 60 | 60 | 60 | 60 |
| CP35E | 8 | 8 | 8 | 8 |
| CP37E | 60 | 60 | 60 | 60 |

Table 7.12 Base Flow Standards (cfs) in the Guadalupe River Basin

| WAM CP ID | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| CP01E | 110 | 100 | 75 | 110 |
| CP02E | 160 | 160 | 110 | 150 |
| CP08E | 52 | 64 | 56 | 64 |
| CP10E | 210 | 220 | 220 | 200 |
| CP11E | 12 | 10 | 5 | 8 |
| C38461E | 796 | 791 | 727 | 746 |
| CP13E | 12 | 9 | 4 | 9 |
| CP14E | 980 | 940 | 800 | 870 |
| CP15E | 975 | 945 | 795 | 865 |

Table 7.13 Base Flow Standards (cfs) in the San Antonio River Basin

| WAM CP ID | Winter | | | Spring | | | Summer | | | Fall | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Avg | Wet | Dry | Avg | Wet | Dry | Avg | Wet | Dry | Avg | Wet |
| P38241E | 17 | 32 | 54 | 10 | 22 | 48 | 6 | 16 | 41 | 16 | 33 | 49 |
| CP28E | 20 | 53 | 71 | 37 | 62 | 77 | 33 | 57 | 72 | 27 | 60 | 74 |
| CP29E | 115 | 262 | 328 | 106 | 237 | 364 | 87 | 178 | 341 | 92 | 223 | 367 |
| CP32E | 152 | 292 | 424 | 137 | 264 | 467 | 113 | 199 | 430 | 117 | 246 | 479 |
| CP35E | 20 | 28 | 39 | 16 | 28 | 44 | 11 | 20 | 37 | 13 | 24 | 40 |
| CP37E | 200 | 329 | 469 | 174 | 313 | 502 | 139 | 237 | 481 | 167 | 280 | 584 |

Table 7.14 lists high flow pulse standard in the GSA River Basins. For control points in the Guadalupe River Basin and control points P38241E and CP28E in the San Antonio River Basin, two "small" and one "large" high flow pulse events per season are specified (Wurbs *et al.*, 2014c). For the remaining four control points in the San Antonio River Basin, one or two "small" and two or three "large" pulses per season are specified (Wurbs *et al.*, 2014c).

Table 7.14 also lists the months included in each season for the "large" pulse events differ from those for the other environmental flow components. Water right permits issued after the effective date of the environmental flow standards are not required to protect a high flow pulse event if the diversion rate for the water right is less than 20% of the trigger magnitude for the high flow pulse event (Wurbs *et al.*, 2014c).

Table 7.14 High Flow Pulse Standards for the GSA River Basins

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| CP01E | Winter | Trigger (cfs) | 140 | 350 |
| | | Volume (ac-ft) | 1,030 | 3,390 |
| | | Duration (days) | 11 | 20 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 400 | 1,190 |
| | | Volume (ac-ft) | 2,980 | 8,950 |
| | | Duration (days) | 17 | 26 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 160 | 570 |
| | | Volume (ac-ft) | 1,130 | 4,110 |
| | | Duration (days) | 12 | 19 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 160 | 500 |
| | | Volume (ac-ft) | 1,110 | 4,060 |
| | | Duration (days) | 13 | 24 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| CP02E | Winter | Trigger (cfs) | 210 | 570 |
| | | Volume (ac-ft) | 1,520 | 5,150 |
| | | Duration (days) | 11 | 19 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 870 | 2,310 |
| | | Volume (ac-ft) | 6,500 | 17,500 |
| | | Duration (days) | 19 | 26 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 240 | 870 |
| | | Volume (ac-ft) | 1,520 | 5,970 |
| | | Duration (days) | 11 | 19 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 230 | 1,000 |
| | | Volume (ac-ft) | 1,660 | 8,060 |
| | | Duration (days) | 12 | 23 |
| | | Frequency | 2 | 1 |
| CP08E | Winter | Trigger (cfs) | 54 | 380 |
| | | Volume (ac-ft) | 360 | 3,840 |
| | | Duration (days) | 10 | 28 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 360 | 960 |
| | | Volume (ac-ft) | 2,370 | 6,540 |
| | | Duration (days) | 18 | 26 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 74 | 190 |
| | | Volume (ac-ft) | 410 | 1,130 |
| | | Duration (days) | 9 | 13 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 82 | 440 |
| | | Volume (ac-ft) | 500 | 3,220 |
| | | Duration (days) | 10 | 21 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| CP10E | Winter | Trigger (cfs) | 340 | 1,330 |
| | | Volume (ac-ft) | 1,800 | 11,400 |
| | | Duration (days) | 8 | 23 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 1,140 | 1,999 |
| | | Volume (ac-ft) | 6,800 | 18,000 |
| | | Duration (days) | 14 | 21 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 240 | 500 |
| | | Volume (ac-ft) | 1,090 | 2,670 |
| | | Duration (days) | 6 | 9 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 540 | 1,710 |
| | | Volume (ac-ft) | 2,740 | 11,200 |
| | | Duration (days) | 9 | 18 |
| | | Frequency | 2 | 1 |
| CP11E | Winter | Trigger (cfs) | 350 | 1,470 |
| | | Volume (ac-ft) | 1,800 | 6,870 |
| | | Duration (days) | 17 | 23 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 720 | 2,100 |
| | | Volume (ac-ft) | 3,300 | 8,860 |
| | | Duration (days) | 17 | 21 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 48 | 230 |
| | | Volume (ac-ft) | 230 | 1,080 |
| | | Duration (days) | 10 | 15 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 150 | 750 |
| | | Volume (ac-ft) | 720 | 3,280 |
| | | Duration (days) | 13 | 17 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| C38461E | Winter | Trigger (cfs) | 1,150 | 4,140 |
| | | Volume (ac-ft) | 9,640 | 48,300 |
| | | Duration (days) | 13 | 29 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 3,250 | 4,154 |
| | | Volume (ac-ft) | 26,900 | 50,000 |
| | | Duration (days) | 17 | 24 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 950 | 1,760 |
| | | Volume (ac-ft) | 7,060 | 14,800 |
| | | Duration (days) | 10 | 14 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 1,410 | 4,154 |
| | | Volume (ac-ft) | 11,400 | 41,200 |
| | | Duration (days) | 13 | 23 |
| | | Frequency | 2 | 1 |
| CP13E | Winter | Trigger (cfs) | 300 | 770 |
| | | Volume (ac-ft) | 1,880 | 4,840 |
| | | Duration (days) | 16 | 21 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 440 | 770 |
| | | Volume (ac-ft) | 2,710 | 4,840 |
| | | Duration (days) | 18 | 21 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 59 | 250 |
| | | Volume (ac-ft) | 330 | 1,430 |
| | | Duration (days) | 11 | 16 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 150 | 570 |
| | | Volume (ac-ft) | 960 | 3,650 |
| | | Duration (days) | 14 | 18 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| CP14E | Winter | Trigger (cfs) | 1,610 | 4,610 |
| | | Volume (ac-ft) | 14,100 | 55,300 |
| | | Duration (days) | 13 | 26 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 3,370 | 8,870 |
| | | Volume (ac-ft) | 31,800 | 100,000 |
| | | Duration (days) | 18 | 30 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 1,050 | 2,110 |
| | | Volume (ac-ft) | 8,300 | 19,300 |
| | | Duration (days) | 12 | 17 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 1,730 | 5,200 |
| | | Volume (ac-ft) | 14,100 | 54,700 |
| | | Duration (days) | 13 | 23 |
| | | Frequency | 2 | 1 |
| CP15E | Winter | Trigger (cfs) | 1,690 | 3,240 |
| | | Volume (ac-ft) | 14,400 | 33,000 |
| | | Duration (days) | 13 | 18 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 3,240 | 3,240 |
| | | Volume (ac-ft) | 33,000 | 43,500 |
| | | Duration (days) | 18 | 25 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 1,040 | 2,060 |
| | | Volume (ac-ft) | 8,570 | 19,200 |
| | | Duration (days) | 11 | 16 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 1,880 | 3,240 |
| | | Volume (ac-ft) | 15,600 | 35,500 |
| | | Duration (days) | 13 | 23 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| P38241E | Winter | Trigger (cfs) | 53 | 110 |
| | | Volume (ac-ft) | 400 | 960 |
| | | Duration (days) | 12 | 17 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 110 | 480 |
| | | Volume (ac-ft) | 900 | 4,190 |
| | | Duration (days) | 17 | 28 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 94 | 340 |
| | | Volume (ac-ft) | 670 | 2,310 |
| | | Duration (days) | 14 | 21 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 68 | 220 |
| | | Volume (ac-ft) | 500 | 1,930 |
| | | Duration (days) | 14 | 24 |
| | | Frequency | 2 | 1 |
| CP28E | Winter | Trigger (cfs) | 120 | 350 |
| | | Volume (ac-ft) | 970 | 3,570 |
| | | Duration (days) | 15 | 27 |
| | | Frequency | 2 | 1 |
| | Spring | Trigger (cfs) | 380 | 1,000 |
| | | Volume (ac-ft) | 2,680 | 7,950 |
| | | Duration (days) | 17 | 27 |
| | | Frequency | 2 | 1 |
| | Summer | Trigger (cfs) | 140 | 440 |
| | | Volume (ac-ft) | 860 | 3,050 |
| | | Duration (days) | 12 | 21 |
| | | Frequency | 2 | 1 |
| | Fall | Trigger (cfs) | 130 | 450 |
| | | Volume (ac-ft) | 930 | 3,890 |
| | | Duration (days) | 14 | 28 |
| | | Frequency | 2 | 1 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow Small | Pulse Flow Large |
|---|---|---|---|---|
| CP29E | Winter | Trigger (cfs) | 830 | |
| | | Volume (ac-ft) | 6,210 | |
| | | Duration (days) | 14 | |
| | | Frequency | 1 | |
| | Spring | Trigger (cfs) | 1,560 | |
| | | Volume (ac-ft) | 10,700 | |
| | | Duration (days) | 16 | |
| | | Frequency | 1 | |
| | Summer | Trigger (cfs) | 1,110 | |
| | | Volume (ac-ft) | 6,460 | |
| | | Duration (days) | 12 | |
| | | Frequency | 1 | |
| | Fall | Trigger (cfs) | 1,010 | |
| | | Volume (ac-ft) | 6,570 | |
| | | Duration (days) | 13 | |
| | | Frequency | 1 | |
| | April through June | Trigger (cfs) | | 3,000 |
| | | Volume (ac-ft) | | 6,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 3 |
| | May through June | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |
| | July through November | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow Small | Pulse Flow Large |
|---|---|---|---|---|
| CP32E | Winter | Trigger (cfs) | 830 | |
| | | Volume (ac-ft) | 6,330 | |
| | | Duration (days) | 16 | |
| | | Frequency | 1 | |
| | Spring | Trigger (cfs) | 1,670 | |
| | | Volume (ac-ft) | 12,300 | |
| | | Duration (days) | 19 | |
| | | Frequency | 1 | |
| | Summer | Trigger (cfs) | 1,030 | |
| | | Volume (ac-ft) | 6,440 | |
| | | Duration (days) | 14 | |
| | | Frequency | 1 | |
| | Fall | Trigger (cfs) | 850 | |
| | | Volume (ac-ft) | 5,690 | |
| | | Duration (days) | 14 | |
| | | Frequency | 1 | |
| | April through June | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 3 |
| | February through April | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |
| | July through November | Trigger (cfs) | | 6,500 |
| | | Volume (ac-ft) | | 13,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow Small | Pulse Flow Large |
|---|---|---|---|---|
| CP35E | Winter | Trigger (cfs) | 570 | |
| | | Volume (ac-ft) | 3,200 | |
| | | Duration (days) | 20 | |
| | | Frequency | 1 | |
| | Spring | Trigger (cfs) | N/A | |
| | | Volume (ac-ft) | N/A | |
| | | Duration (days) | N/A | |
| | | Frequency | N/A | |
| | Summer | Trigger (cfs) | 390 | |
| | | Volume (ac-ft) | 1,990 | |
| | | Duration (days) | 15 | |
| | | Frequency | 1 | |
| | Fall | Trigger (cfs) | 190 | |
| | | Volume (ac-ft) | 1,000 | |
| | | Duration (days) | 13 | |
| | | Frequency | 2 | |
| | April through June | Trigger (cfs) | | 1,000 |
| | | Volume (ac-ft) | | 2,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 3 |
| | July through October | Trigger (cfs) | | 1,000 |
| | | Volume (ac-ft) | | 2,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |
| | July through November | Trigger (cfs) | | 2,500 |
| | | Volume (ac-ft) | | 5,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |

Table 7.14 (Continued)

| WAM CP ID | Season | Pulse Flow Criteria | Pulse Flow | |
|---|---|---|---|---|
| | | | Small | Large |
| CP37E | Winter | Trigger (cfs) | 1,520 | |
| | | Volume (ac-ft) | 12,800 | |
| | | Duration (days) | 19 | |
| | | Frequency | 1 | |
| | Spring | Trigger (cfs) | 1,570 | |
| | | Volume (ac-ft) | 11,300 | |
| | | Duration (days) | 16 | |
| | | Frequency | 2 | |
| | Summer | Trigger (cfs) | 1,640 | |
| | | Volume (ac-ft) | 11,200 | |
| | | Duration (days) | 16 | |
| | | Frequency | 1 | |
| | Fall | Trigger (cfs) | 2,320 | |
| | | Volume (ac-ft) | 17,600 | |
| | | Duration (days) | 19 | |
| | | Frequency | 1 | |
| | April through June | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 3 |
| | February through April | Trigger (cfs) | | 4,000 |
| | | Volume (ac-ft) | | 8,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |
| | July through November | Trigger (cfs) | | 8,000 |
| | | Volume (ac-ft) | | 16,000 |
| | | Duration (days) | | 2 |
| | | Frequency | | 2 |

## 7.2 Modeling Environmental Flow Standards

Wurbs and Hoffpauir (2013b) outline capabilities for incorporating environmental flow standards into water availability modeling using the new daily WRAP/WAM modeling system. This section briefly introduces the methodologies that were recently employed to model the SB3 environmental flow standards in the three daily WAM reports (Wurbs *et al.*, 2014a, 2014b and 2014c). Thus, detailed explanations for each record, used for the SB3 modeling for the three daily WAMs can be referred to the three report of "Daily Water Availability Model for the Sabine, Neches, GSA River Basins", respectively. The evaluations of environmental flow standards for the basins are performed through the modification of the options based on the three daily WAM systems.

### 7.2.1 Sabine WAM

The method for modeling of environmental flow standards in the Sabine WAM is illustrated by the input records used to model the instream flow requirements for control point BSBSE, as an example of modeling. The same modeling methodology was used for all five control points as follows:

- Target setting water right *WR* records along with flow switch *FS*, target options *TO*, daily data *DW*, and daily options *DO* records explained in the WRAP user manuals were used for the modeling of subsistence and base flow standards.
- A target setting water right *WR* record in combination with pulse flow *PF* records and pulse flow options *PO* records was used for the modeling of pulse flow standards.
- An instream flow *IF* record with a target equal to the maximum of the targets set by the target setting water right records was used for setting the instream flow target.
- A priority number of 50000000 was assigned to the water rights modeling the SB3 instream flow standards to make them junior to all other water rights in the WAM.

The flow standards have a priority date of November 30, 2009. However, there water rights related to the sharing of Toledo Bend by the states of Texas and Louisiana that are modeled with a priority of 30001231 to designate them as being junior to other rights in the Sabine WAM includes. Therefore, the SB3 environmental flow standards are assigned a priority of 50000000 to make them the most junior rights in the WAM (Wurbs *et al.*, 2014a). Table 7.15 summarizes the environmental flow standards for control point BSBSE, Big Sandy Creek near Big Sandy, that consist of seasonal subsistence flow, base flow, and high flow pulse requirements.

Table 7.15 Environmental Flow Standards for Control Point BSBSE

| Season | Subsistence (cfs) | Base (cfs) | Pulse | |
|---|---|---|---|---|
| Winter | 20 | 73 | Trigger (cfs): | 358 |
| | | | Volume (ac-ft): | 5,932 |
| | | | Duration (days): | 10 |
| | | | Frequency | 1 |
| Spring | 9 | 33 | Trigger (cfs): | 313 |
| | | | Volume (ac-ft): | 5,062 |
| | | | Duration (days): | 13 |
| | | | Frequency | 2 |
| Summer | 8 | 15 | Trigger (cfs): | 50 |
| | | | Volume (ac-ft): | 671 |
| | | | Duration (days): | 6 |
| | | | Frequency | 1 |
| Fall | 8 | 22 | Trigger (cfs): | 130 |
| | | | Volume (ac-ft): | 2,189 |
| | | | Duration (days): | 9 |
| | | | Frequency | 2 |

Table 7.16 reproduces the input records used for modeling the environmental flow standards for control point BSBSE. These are categorized into four sections as follows (Wurbs *et al.*, 2014a):

Section 1. Use coefficient *UC* records are used to identify the months in each season.

Section 2. Daily subsistence and base flow targets are set. Eight target setting water rights are implemented corresponding to subsistence and base flow targets for four seasons.

Section 3. The daily high flow pulse target is set using a target setting water right and a series of *PF* and *PO* records. A target of zero is set if no pulse events are triggered.

Section 4. The final daily instream flow target is set. An instream flow *IF* record adopts the maximum target set by the target setting water rights from Sections 2 and 3.

Table 7.16 Input Records for Environmental Flow Standards for Control Point BSBSE

```
**
** Section 1 - Use coefficient records used to identify seasons
**
UCWINTER       1       1       1       0       0       0
UC             0       0       0       0       0       0
UCSPRING       0       0       0       1       1       1
UC             0       0       0       0       0       0
UCSUMMER       0       0       0       0       0       0
UC             1       1       1       0       0       0
UC  FALL       0       0       0       0       0       0
UC             0       0       0       1       1       1
**
** Section 2 - Subsistence and base flow targets
**
** Subsistence flows
WR BSBSE 9999999  WINTER50000000   8                            BSBSE_SUB_WIN
TO    15  39.669     MIN
DO       16
WR BSBSE 9999999  SPRING50000000   8                            BSBSE_SUB_SPR
TO    15  17.851     MIN
DO       16
WR BSBSE 9999999  SUMMER50000000   8                            BSBSE_SUB_SMR
TO    15  15.868     MIN
DO       16
WR BSBSE 9999999    FALL50000000   8                            BSBSE_SUB_FAL
TO    15  15.868     MIN
DO       16
** Base flows
WR BSBSE  434.38  WINTER50000000   8                            BSBSE_BASE_WIN
FS     1            0.0     1.0         144.79   1          0          1
DO                 19
DW        2
WR BSBSE  196.36  SPRING50000000   8                            BSBSE_BASE_SPR
FS     1            0.0     1.0          65.45   1          0          1
DO                 19
DW        2
WR BSBSE   89.26  SUMMER50000000   8                            BSBSE_BASE_SMR
```

Table 7.16 (Continued)

```
FS     1           0.0     1.0          29.75   1          0          1
DO               19
DW        2
WR BSBSE  130.91    FALL50000000   8                         BSBSE_BASE_FAL
FS     1           0.0     1.0          43.64   1          0          1
DO               19
DW        2
WR BSBSE       0        50000000   8                         BSBSE_BASEFLOW
TO    13           MAX                             BSBSE_SUB_WIN   CONT
TO    13           MAX                             BSBSE_SUB_SPR   CONT
TO    13           MAX                             BSBSE_SUB_SMR   CONT
TO    13           MAX                             BSBSE_SUB_FAL   CONT
TO    13           MAX                             BSBSE_BASE_WIN  CONT
TO    13           MAX                             BSBSE_BASE_SPR  CONT
TO    13           MAX                             BSBSE_BASE_SMR  CONT
TO    13           MAX                             BSBSE_BASE_FAL
DO       16
** Section 3 - Pulse flow targets
** Pulse flows
WR BSBSE       0        50000000   8                         BSBSE_PULSE
PF     0   BSBSE 710.083    5932  10   1          1   3          2   4
BSBSE_WIN
PO           2
PF     0   BSBSE 620.826    5062  13   2          4   6          2   4
BSBSE_SPR
PO           2
PF     0   BSBSE  99.174     671   6   1          7   9          2   4
BSBSE_SMR
PO           2
PF     0   BSBSE 257.851    2189   9   2         10  12          2   4
BSBSE_FAL
PO           2
** Section 4 - Final instream flow target
IF BSBSE       0        50000000   2          IF-BSBSE
TO    13           MAX                             BSBSE_BASEFLOW  CONT
TO    13           MAX                             BSBSE_PULSE
DO       16
**
```

### 7.2.2 Neches WAM

Table 7.17 reproduces the input records used to model the instream flow requirements for control point NENEE for demonstration purposes. The same modeling methodology was also used for all five control points. The SB3 environmental flow standards for the Neches WAM are the same as the Sabine WAM expect for a priority number of 20091130 that was used for all instream flow *IF* and water right *WR* records, corresponding to a priority date of November 30, 2009.

Table 7.17 Input Records for Environmental Flow Standards

for Control Point NENEE

```
** Section 1 - Use coefficient records used to identify seasons
UCWINTER       1       1       1       0       0       0
UC             0       0       0       0       0       0
UCSPRING       0       0       0       1       1       1
UC             0       0       0       0       0       0
UCSUMMER       0       0       0       0       0       0
UC             1       1       1       0       0       0
UC  FALL       0       0       0       0       0       0
UC             0       0       0       1       1       1
**
** CP: NENEE,  08032000,  Neches River at Neches
** Section 2 - Subsistence and Base flow Targets
** - Subsistence flows
WR NENEE 9999999  WINTER20091130   8
NENEE_SUB_WIN
TO    15 101.157     MIN
DO        16
WR NENEE 9999999  SPRING20091130   8
NENEE_SUB_SPR
TO    15  41.653     MIN
DO        16
WR NENEE 9999999  SUMMER20091130   8
NENEE_SUB_SMR
TO    15  23.802     MIN
DO        16
WR NENEE 9999999    FALL20091130   8
NENEE_SUB_FAL
TO    15  25.785     MIN
DO        16
**- Base flows
WR NENEE 1166.28  WINTER20091130   8
NENEE_BASE_WIN
FS     1             0.0     1.0          388.76   1           0
1
DO                19
DW         2
WR NENEE  571.24  SPRING20091130   8
NENEE_BASE_SPR
FS     1             0.0     1.0          190.41   1           0
1
DO                19
DW         2
WR NENEE  273.72  SUMMER20091130   8
NENEE_BASE_SMR
```

Table 7.17 (Continued)

```
FS      1              0.0     1.0           91.24   1           0
1
DO                  19
DW          2
WR NENEE  476.03    FALL20091130   8
NENEE_BASE_FAL
FS      1              0.0     1.0          158.68   1           0
1
DO                  19
DW          2
WR NENEE       0        20091130   8
NENEE_BASEFLOW
TO     13              MAX                                NENEE_SUB_WIN
CONT
TO     13              MAX                                NENEE_SUB_SPR
CONT
TO     13              MAX                                NENEE_SUB_SMR
CONT
TO     13              MAX                                NENEE_SUB_FAL
CONT
TO     13              MAX                                NENEE_BASE_WIN
CONT
TO     13              MAX                                NENEE_BASE_SPR
CONT
TO     13              MAX                                NENEE_BASE_SMR
CONT
TO     13              MAX                                NENEE_BASE_FAL
DO          16
** Section 3 - Pulse flow targets
WR NENEE       0        20091130   8                                  NENEE_PULSE
PF     0   NENEE1652.231   19104  10   1         1   3         2   4
NENEE_WIN
PO           2
PF     0   NENEE1626.446   20405  12   2         4   6         2   4
NENEE_SPR
PO           2
PF     0   NENEE 224.132    1339   4   1         7   9         2   4
NENEE_SMR
PO           2
PF     0   NENEE 684.298    5391   8   2        10  12         2   4
NENEE_FAL
PO           2
** Section 4 - Final instream flow target
IF NENEE       0        20091130   2            IF-NENEE
TO     13              MAX                                NENEE_BASEFLOW
CONT
TO     13              MAX                                NENEE_PULSE
DO          16
**
```

The environmental flow standards for control point NENEE also have seasonal subsistence flow, base flow, and high flow pulse requirements as shown in Table 7.18. The category of the input records is also the same as the Sabine WAM. Detailed

Table 7.18 Environmental Flow Standards for Control Point NENEE

| Season | Subsistence (cfs) | Base (cfs) | Pulse | |
|---|---|---|---|---|
| Winter | 51 | 196 | Trigger (cfs): | 833 |
| | | | Volume (ac-ft): | 19,104 |
| | | | Duration (days): | 10 |
| | | | Frequency | 1 |
| Spring | 21 | 96 | Trigger (cfs): | 820 |
| | | | Volume (ac-ft): | 20,405 |
| | | | Duration (days): | 12 |
| | | | Frequency | 2 |
| Summer | 12 | 46 | Trigger (cfs): | 113 |
| | | | Volume (ac-ft): | 1,339 |
| | | | Duration (days): | 4 |
| | | | Frequency | 1 |
| Fall | 13 | 80 | Trigger (cfs): | 345 |
| | | | Volume (ac-ft): | 5,391 |
| | | | Duration (days): | 8 |
| | | | Frequency | 2 |

### 7.2.3 GSA WAM

Two sets of input records are included in this section to illustrate the alternate methodologies employed for modeling environmental flow standards at control points located in the Guadalupe River Basin and control points in the San Antonio River Basin for which different approaches were used to define hydrologic conditions (Wurbs *et al.*, 2014c). Even though the modeling methodology was more complicated for control points in the San Antonio River Basin, a similar paradigm was implemented in both basins. The same modeling methodology was used for all fifteen control points as follows:

- Subsistence and base flow standards were modeled using target setting water right *WR* records in combination with flow switch *FS*, target options *TO*, daily data *DW*, and daily options *DO* records.
- Pulse flow standards were modeled using a target setting water right *WR* record in combination with pulse flow *PF* records and pulse flow options *PO* records.
- The instream flow target was set using an instream flow *IF* record with a target equal to the maximum of the targets set by the target setting water right records.
- A priority of 88888888 was used for the instream flow rights modeling SB3 environmental flow standards to make them junior to all other water rights. Three existing rights have priorities of 88888801, 88888802, and 88888803, which are junior to the actual priority date of March 1, 2011 for the SB3 flow standards.

*Control points in the Guadalupe River Basin*

Control point CP14E represents the control points in the Guadalupe River Basin. Table 7.19 tabulates The environmental flow standards for this location consist of subsistence and base flows that vary seasonally, a two-per-season high flow pulse, and a one-per-season high flow pulse. The input records for modeling the winter subsistence, base, and pulse flow requirements are representatively reproduced as listed Table 7.20. Similar records for other seasons have been omitted for brevity. The input records used for modeling the environmental flow standards for control point CP14E for the winter season are categorized as follows (Wurbs *et al.*, 2014c):

Section 1. A use coefficient *UC* record is used to identify the months in the winter season.

Section 2. Daily subsistence and base flow targets for the winter season are set. Three target setting water rights are used corresponding to the winter subsistence flow, the winter base flow, and intermediate flows between the winter subsistence and base flows.

Section 3. Daily high flow pulse targets for the winter season are set. A target setting water right adopts the maximum target set by a series of *PF* and *PO* records. A target of zero is set if no high flow pulse events are triggered.

Section 4. The daily instream flow target for the winter season is set. An *IF* record adopts the maximum target set by the target setting water rights from Sections 2 and 3.

Table 7.19 Environmental Flow Standards for Control Point CP14E

| Season | Subsistence (cfs) | Base (cfs) | | Small Seasonal Pulse Events | Large Seasonal Pulse Events |
|---|---|---|---|---|---|
| Winter | 130 | 980 | Trigger (af/day) | 1,610 | 4,610 |
| | | | Volume (ac-ft) | 14,100 | 55,300 |
| | | | Duration (days) | 13 | 26 |
| | | | Frequency | 2 | 1 |
| Spring | 120 | 940 | Trigger (cfs) | 3,370 | 8,870 |
| | | | Volume (ac-ft) | 31,800 | 100,000 |
| | | | Duration (days) | 18 | 30 |
| | | | Frequency | 2 | 1 |
| Summer | 130 | 800 | Trigger (cfs) | 1,050 | 2,110 |
| | | | Volume (ac-ft) | 8,300 | 19,300 |
| | | | Duration (days) | 12 | 17 |
| | | | Frequency | 2 | 1 |
| Fall | 86 | 870 | Trigger (cfs) | 1,730 | 5,200 |
| | | | Volume (ac-ft) | 14,100 | 54,700 |
| | | | Duration (days) | 13 | 23 |
| | | | Frequency | 2 | 1 |

Table 7.20 Input Records for Environmental Flow Standards

at Control Point CP14E for the Winter Season

```
**
** Section 1 - Use Type Records for the Winter Season
**
UC   WIN       1       1       1       0       0       0       0       0       0
0       0       0
**
** Section 2 - Subsistence and Base Flow Targets for the Winter Season
**
WR CP14E     3.0     WIN88888888   8                           CP14E_WIN
DW         2
WR CP14E  773.55     WIN88888888   8                           CP14E_SUB_WIN
FS                   0.0     1.0  257.85           1           0
DO                19
DW         2
WR CP14E  773.55     WIN88888888   8                           CP14E_SUBBAS_WIN
TO     2             ADD                                                   CONT
TO    15     0.5     MUL                                                   CONT
TO    13             MUL                                   CP14E_WIN
FS                   1.0     0.0  257.85 1943.80   1           0
DO        16      19
DW         2
WR CP14E 5831.40     WIN88888888   8                           CP14E_BAS_WIN
FS                   0.0     1.0         1943.80   1           0
DO                19
DW         2
**
** Section 3 - High Flow Pulse Event Targets for the Winter Season
**
WR CP14E       0        88888888   8                           CP14E_PULSE
PF     0         3193.39   14100  13   2           1   3           2   4
CP14E_WINTER_S
PO             2
PF     0         9143.80   55300  26   1           1   3           2   4
CP14E_WINTER_L
PO             2
**
** Section 4 - Final Daily Instream Flow Target for the Winter Season
**
IF CP14E                88888888   2           IF-CP14E
TO    13             MAX                               CP14E_SUB_WIN   CONT
TO    13             MAX                               CP14E_SUBBAS_WINCONT
TO    13             MAX                               CP14E_BAS_WIN   CONT
TO    13             MAX                               CP14E_PULSE
DO        16
```

*Control points in the San Antonio River Basin*

Control point CP37E (USGS Gage 08188500) represents the control points in the San Antonio River. This control point also has the environmental flow standards that consist of subsistence and base flows that vary seasonally and according to hydrologic conditions, a set of small seasonal high flow pulses, and three large inter-seasonal high flow pulses, as listed in Table 7.21. The three levels of hydrologic conditions (dry, average, and wet) are evaluated using the hydrologic index series (HIS) input file (Wurbs *et al.*, 2014c).

Table 7.21 Environmental Flow Standards for Control Point CP37E

| Season | Hydrologic Condition | Subsistence (cfs) | Base (cfs) | Small Seasonal Pulse Events | |
|---|---|---|---|---|---|
| Winter | Dry | 60 | 200 | Trigger (cfs) | 1,520 |
| | Average | N/A | 329 | Volume (ac-ft) | 12,800 |
| | Wet | N/A | 469 | Duration (days) | 19 |
| | | | | Frequency | 1 |
| Spring | Dry | 60 | 174 | Trigger (cfs) | 1,570 |
| | Average | N/A | 313 | Volume (ac-ft) | 11,300 |
| | Wet | N/A | 502 | Duration (days) | 16 |
| | | | | Frequency | 2 |
| Summer | Dry | 60 | 139 | Trigger (cfs) | 1,640 |
| | Average | N/A | 237 | Volume (ac-ft) | 11,200 |
| | Wet | N/A | 481 | Duration (days) | 16 |
| | | | | Frequency | 1 |
| Fall | Dry | 60 | 167 | Trigger (cfs) | 2,320 |
| | Average | N/A | 280 | Volume (ac-ft) | 17,600 |
| | Wet | N/A | 584 | Duration (days) | 19 |
| | | | | Frequency | 1 |

Table 7.21 (Continued)

| Season | Hydrologic Condition | Subsistence (cfs) | Base (cfs) | Small Seasonal Pulse Events | |
|---|---|---|---|---|---|
| Large Pulse Events | | | | | |
| April through June | | | | Trigger (cfs) | 4,000 |
| | | | | Volume (ac-ft) | 15,867 |
| | | | | Duration (days) | 2 |
| | | | | Frequency | 3 |
| February through April | | | | Trigger (cfs) | 4,000 |
| | | | | Volume (ac-ft) | 15,867 |
| | | | | Duration (days) | 2 |
| | | | | Frequency | 2 |
| July through November | | | | Trigger (cfs) | 8,000 |
| | | | | Volume (ac-ft) | 31,735 |
| | | | | Duration (days) | 2 |
| | | | | Frequency | 2 |

Table 7.22 describes the input records for modeling the subsistence, base flow, and high flow pulse event requirements for the winter season at control point CP37E (Wurbs *et al.*, 2014c). These are the same as the input records for the spring, summer, and fall seasons. The input records are divided into the five sections as follows (Wurbs *et al.*, 2014c):

Section 1. Use coefficient *UC* records and a target setting water right *WR* record are used to set subsistence and base flow targets for the winter season.

Section 2. Hydrologic conditions are evaluated using information from the hydrologic index series (HIS) input file. The hydrologic conditions are evaluated once per season based on conditions on the last day of the preceding season.

Section 3. Daily subsistence and base flow targets for the winter season are set. Five target setting water rights are implemented, corresponding to the winter subsistence flow, the winter base flows for three hydrologic conditions, and intermediate flows between the winter subsistence and base flows.

Section 4. Daily high flow pulse event targets are set. A target setting water right adopts the maximum target set by a series of *PF* and *PO* records. A target of zero is set if no high flow pulse events are triggered.

Section 5. The final daily instream flow target for the winter season is set. An instream flow *IF* record adopts the maximum target set by the target setting water rights from Sections 3 and 4.

Table 7.22 Input Records for Environmental Flow Standards
at Control Point CP37E for the Winter Season

```
**
** Section 1 - Use Coefficients and Water Right Target for the Winter Season
**
UC   WIN      1      1      1      0      0      0      0      0      0      0      0      0
UCBEGWIN      1      0      0      0      0      0      0      0      0      0      0      0
**
WR CP37E    3.0    WIN88888888   8                          CP37E_WIN
DW        2
**
** Section 2 - Evaluation of Hydrologic Conditions for the Winter Season
**
WR CP37E               88888888   8                          CP37E_HYDCOND
TO   -16
DO       16
WR CP37E    1.0        88888888   8                          CP37E_ANREG_DRY
FS    10           1.0    0.0    0.9    1.1   1                                     CP37E_HYDCOND
DO              19
DW        1
WR CP37E    1.0        88888888   8                          CP37E_ANREG_AVG
FS    10           1.0    0.0    1.9    2.1   1                                     CP37E_HYDCOND
DO              19
DW        1
WR CP37E    1.0        88888888   8                          CP37E_ANREG_WET
FS    10           1.0    0.0    2.9    3.1   1                                     CP37E_HYDCOND
DO              19
DW        1
WR CP37E    1.0  BEGWIN88888888   8                          CP37E_WIN_DRY
TO    13           MUL                                  CP37E_ANREG_DRY
DO       16
DW        2   1
WR CP37E    1.0  BEGWIN88888888   8                          CP37E_WIN_AVG
TO    13           MUL                                  CP37E_ANREG_AVG
DO       16
DW        2   1
WR CP37E    1.0  BEGWIN88888888   8                          CP37E_WIN_WET
TO    13           MUL                                  CP37E_ANREG_WET
DO       16
```

Table 7.22 (Continued)

```
DW        2  1
**
** Section 3 - Subsistence and Base Flow Targets for the Winter Season
**
WR CP37E  357.02     WIN88888888   8                           CP37E_SUB_WIN
FS    10            1.0     0.0     1.0           1         92              CP37E_WIN_DRY
FS     1            0.0     1.0  119.01           1          0
DO               19
DW        2
WR CP37E  357.02     WIN88888888   8                           CP37E_SUBBAS_WIN
TO     2            ADD                                                    CONT
TO    15    0.5     MUL                                                    CONT
TO    13            MUL                                  CP37E_WIN
FS    10            1.0     0.0     1.0           1         92              CP37E_WIN_DRY
FS     1            1.0     0.0  119.01  396.69   1          0
DO        16     19
DW        2
WR CP37E 1190.08     WIN88888888   8                           CP37E_BASED_WIN
FS    10            1.0     0.0     1.0           1         92              CP37E_WIN_DRY
FS     1            0.0     1.0          396.69   1          0
DO               19
DW        2
WR CP37E 1957.69     WIN88888888   8                           CP37E_BASEA_WIN
FS    10            1.0     0.0     1.0           1         92              CP37E_WIN_AVG
DO               19
DW        2
WR CP37E 2790.74     WIN88888888   8                           CP37E_BASEW_WIN
FS    10            1.0     0.0     1.0           1         92              CP37E_WIN_WET
DO               19
DW        2
**
** Section 4 - High Flow Pulse Event Targets for the Winter Season
**
WR CP37E       0        88888888   8                           CP37E_PULSE
PF     0         3014.88   12800  19   1          1   3          2   4                CP37E_WINTER_S
PF     0         3114.05   11300  16   2          4   6          2   4                CP37E_SPRING_S
PF     0         3252.89   11200  16   1          7   9          2   4                CP37E_SUMMER_S
PF     0         4601.65   17600  19   1         10  12          2   4                CP37E_FALL_S
PF     0         7933.88   15867   2   3          4   6          2   4                CP37E_APRJUN
PO          2
PF     0         7933.88   15867   2   2          2   4          2   4                CP37E_FEBAPR
PO          2
PF     0        15867.77   31735   2   2          7  11          2   4                CP37E_JULNOV
PO          2
**
** Section 5 - Final Daily Instream Flow Target for the Winter Season
**
IF CP37E                88888888   2           IF-CP37E
TO    13            MAX                                  CP37E_SUB_WIN   CONT
TO    13            MAX                                  CP37E_SUBBAS_WINCONT
TO    13            MAX                                  CP37E_BASED_WIN CONT
TO    13            MAX                                  CP37E_BASEA_WIN CONT
TO    13            MAX                                  CP37E_BASEW_WIN CONT
TO    13            MAX                                  CP37E_PULSE
DO        16
```

## 7.3 SB3 Environmental Flow Target

The monthly naturalized datasets, daily flow patterns, water use scenarios, and environmental flow standards in the Sabine, Neches, and GSA River Basins are incorporated in each daily WRAP model for river system simulations. In this section, daily naturalized flows, regulated flows, environmental flow targets and associated shortages in meeting the flow targets at the control points, where the environmental flow standards have been established, are developed by each WAM model for investigating the flow characteristics and alterations. The letter "E" is added to the control point identifiers. The "E" control points have the only water rights that are IF record rights modeling the SB3 environmental flow standards at the same locations of the control points.

Daily naturalized flow sequences are disaggregated based on daily flow patterns that are developed by the calibrated daily SWAT model, described in Chapter VI. A daily WRAP/WAM model develops regulated flows, influencing the naturalized flows by various human impacts such as reservoir storage, water diversions etc. based on water use scenarios using naturalized flow datasets. The environmental flow target adopted each day is the maximum of the high pulse flows target, which is often zero, and the combined subsistence and base flow target.

### 7.3.1 Sabine WAM

The daily WRAP model for the Sabine WAM develops four different daily flow sequences, mentioned above at the five control points, listed in Table 6.2. The simulation covers the period-of-analysis (1940-2013), and a full authorized use scenario is adopted. The flow frequency metrics are developed using the four different daily flow sequences for examining each flow sequence at the five control points.

Table 7.23 presents the flow frequency metrics for naturalized flow, regulated flow, SB3 environmental flow target and shortage in meeting the SB3 environmental target at the control point BSBSE. There is the Winnsboro Lake upstream of the control point, but the flow frequency metrics of both naturalized and regulated flows indicate that the hydrologic alterations are insignificant at the control point.

Table 7.23 Flow Frequency Metrics (acre-feet/day) for Control Point BSBSE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 368.8 | 359.0 | 57.6 | 1.0 | 79.6 | 1.0 |
| Stan Dev | 731.8 | 730.1 | 43.2 | 3.9 | 107.7 | 3.9 |
| Minimum | 0.0 | 0.0 | 15.9 | 0.0 | 15.9 | 0.0 |
| 99.50% | 0.0 | 0.0 | 15.9 | 0.0 | 15.9 | 0.0 |
| 99% | 0.1 | 0.3 | 15.9 | 0.0 | 15.9 | 0.0 |
| 98% | 2.2 | 2.2 | 15.9 | 0.0 | 15.9 | 0.0 |
| 95% | 10.9 | 10.2 | 15.9 | 0.0 | 15.9 | 0.0 |
| 90% | 21.3 | 19.5 | 15.9 | 0.0 | 15.9 | 0.0 |
| 85% | 30.4 | 27.5 | 17.9 | 0.0 | 17.9 | 0.0 |
| 80% | 41.5 | 36.4 | 29.8 | 0.0 | 29.8 | 0.0 |
| 75% | 53.1 | 46.8 | 29.8 | 0.0 | 29.8 | 0.0 |
| 70% | 65.8 | 57.9 | 29.8 | 0.0 | 29.8 | 0.0 |
| 60% | 98.1 | 87.2 | 39.7 | 0.0 | 39.7 | 0.0 |
| 50% | 141.2 | 129.0 | 43.6 | 0.0 | 43.6 | 0.0 |
| 40% | 200.1 | 186.1 | 65.5 | 0.0 | 65.5 | 0.0 |
| 30% | 297.0 | 283.5 | 65.5 | 0.0 | 65.5 | 0.0 |
| 25% | 370.8 | 356.5 | 65.5 | 0.0 | 65.5 | 0.0 |
| 20% | 467.4 | 453.4 | 144.8 | 0.0 | 144.8 | 0.0 |
| 15% | 608.8 | 596.5 | 144.8 | 0.0 | 144.8 | 0.0 |
| 10% | 869.2 | 855.0 | 144.8 | 0.0 | 144.8 | 0.0 |
| 5% | 1,452 | 1,436 | 144.8 | 8.9 | 249.8 | 8.9 |
| 2% | 2,585 | 2,571 | 144.8 | 15.5 | 620.8 | 15.5 |
| 1% | 3,690 | 3,689 | 144.8 | 17.3 | 620.8 | 17.3 |
| 0.50% | 5,071 | 5,064 | 144.8 | 25.2 | 710.1 | 25.2 |
| Maximum | 16,928 | 16,956 | 144.8 | 39.7 | 710.1 | 39.7 |

The regulated flow has totally different flow frequency metrics than the naturalized flow at the control point SRGWE due to water uses and flow controls by the two large dams, as listed in Table 7.24. The regulated flow can meet the environmental flow target engaged by the WRAP model for 90 % of the period-of-analysis at the control point.

Table 7.24 Flow Frequency Metrics (acre-feet/day) for Control Point SRGWE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 4,157 | 2,777 | 221.0 | 2.8 | 396.1 | 2.8 |
| Stan Dev | 6,958 | 5,109 | 207.4 | 10.5 | 724.6 | 10.5 |
| Minimum | 2.9 | 0.0 | 27.8 | 0.0 | 27.8 | 0.0 |
| 99.50% | 11.0 | 0.0 | 27.8 | 0.0 | 27.8 | 0.0 |
| 99% | 15.9 | 0.0 | 27.8 | 0.0 | 27.8 | 0.0 |
| 98% | 25.1 | 0.0 | 27.8 | 0.0 | 27.8 | 0.0 |
| 95% | 49.0 | 0.0 | 27.8 | 0.0 | 27.8 | 0.0 |
| 90% | 109.4 | 33.5 | 33.7 | 0.0 | 33.7 | 0.0 |
| 85% | 194.9 | 81.0 | 43.6 | 0.0 | 43.6 | 0.0 |
| 80% | 297.4 | 138.2 | 73.4 | 0.0 | 73.4 | 0.0 |
| 75% | 410.5 | 210.5 | 73.4 | 0.0 | 73.4 | 0.0 |
| 70% | 544.2 | 292.5 | 73.4 | 0.0 | 73.4 | 0.0 |
| 60% | 939.6 | 532.9 | 107.1 | 0.0 | 107.1 | 0.0 |
| 50% | 1,563 | 932.2 | 107.1 | 0.0 | 107.1 | 0.0 |
| 40% | 2,553 | 1,565 | 259.8 | 0.0 | 259.8 | 0.0 |
| 30% | 4,034 | 2,551 | 259.8 | 0.0 | 259.8 | 0.0 |
| 25% | 4,953 | 3,239 | 605.0 | 0.0 | 605.0 | 0.0 |
| 20% | 6,347 | 4,096 | 605.0 | 0.0 | 605.0 | 0.0 |
| 15% | 8,196 | 5,387 | 605.0 | 0.0 | 605.0 | 0.0 |
| 10% | 10,976 | 7,391 | 605.0 | 0.1 | 605.0 | 0.1 |
| 5% | 16,233 | 11,280 | 605.0 | 27.8 | 2,612 | 27.8 |
| 2% | 25,261 | 17,716 | 605.0 | 33.7 | 3,134 | 33.7 |
| 1% | 34,659 | 24,407 | 605.0 | 43.6 | 3,729 | 43.6 |
| 0.50% | 43,550 | 31,092 | 605.0 | 89.3 | 3,729 | 89.3 |
| Maximum | 109,712 | 108,543 | 605.0 | 89.3 | 3,729 | 89.3 |

The regulated flow decreases considerably relative to the naturalized flow at control point SRBEE due to upstream water uses and flow controls by several dams, as listed in Table 7.25. The shortage of the environmental flow target is 2.0 acre-feet/day in average, and 130.9 acre-feet/day in maximum at the control points.

Table 7.25 Flow Frequency Metrics (acre-feet/day) for Control Point SRBEE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 5,516 | 3,845 | 356.2 | 2.0 | 621.7 | 2.0 |
| Stan Dev | 8,016 | 6,176 | 332.0 | 10.2 | 1,064 | 10.2 |
| Minimum | 2.1 | 0.0 | 43.6 | 0.0 | 43.6 | 0.0 |
| 99.50% | 22.0 | 0.0 | 43.6 | 0.0 | 43.6 | 0.0 |
| 99% | 31.8 | 0.0 | 43.6 | 0.0 | 43.6 | 0.0 |
| 98% | 47.3 | 3.5 | 43.6 | 0.0 | 43.6 | 0.0 |
| 95% | 128.8 | 35.8 | 43.6 | 0.0 | 43.6 | 0.0 |
| 90% | 250.2 | 107.7 | 43.6 | 0.0 | 43.6 | 0.0 |
| 85% | 390.5 | 183.9 | 111.1 | 0.0 | 111.1 | 0.0 |
| 80% | 535.6 | 269.3 | 111.1 | 0.0 | 111.1 | 0.0 |
| 75% | 719.8 | 324.3 | 111.1 | 0.0 | 111.1 | 0.0 |
| 70% | 927.7 | 449.7 | 111.1 | 0.0 | 111.1 | 0.0 |
| 60% | 1,558 | 851.6 | 164.6 | 0.0 | 164.6 | 0.0 |
| 50% | 2,485 | 1,493 | 164.6 | 0.0 | 164.6 | 0.0 |
| 40% | 3,925 | 2,456 | 446.3 | 0.0 | 446.3 | 0.0 |
| 30% | 5,803 | 3,781 | 446.3 | 0.0 | 446.3 | 0.0 |
| 25% | 7,113 | 4,775 | 956.0 | 0.0 | 956.0 | 0.0 |
| 20% | 8,900 | 6,060 | 956.0 | 0.0 | 956.0 | 0.0 |
| 15% | 11,301 | 7,937 | 956.0 | 0.0 | 956.0 | 0.0 |
| 10% | 14,624 | 10,684 | 956.0 | 0.0 | 956.0 | 0.0 |
| 5% | 20,146 | 15,269 | 956.0 | 9.9 | 3,843 | 9.9 |
| 2% | 28,296 | 21,624 | 956.0 | 41.1 | 4,284 | 41.1 |
| 1% | 36,802 | 27,921 | 956.0 | 43.6 | 5,752 | 43.6 |
| 0.50% | 47,837 | 36,448 | 956.0 | 55.5 | 5,752 | 55.5 |
| Maximum | 102,609 | 101,136 | 956.0 | 130.9 | 5,752 | 130.9 |

Both naturalized and regulated flows have almost identical flow frequency metrics at the control point 29500E, as presented in Table 7.26. This means that there are no water uses and flow controllers upstream of the control point. The exceedance frequency of the environmental flow shortage is 15% similar to the control point SRRLE. This is slightly higher than other control points in the Sabine River Basin.

Table 7.26 Flow Frequency Metrics (acre-feet/day) for Control Point 29500E

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 382.6 | 382.6 | 75.3 | 4.0 | 95.0 | 4.0 |
| Stan Dev | 781.9 | 781.9 | 28.8 | 10.7 | 122.1 | 10.7 |
| Minimum | 0.0 | 0.0 | 39.7 | 0.0 | 39.7 | 0.0 |
| 99.50% | 0.0 | 0.0 | 39.7 | 0.0 | 39.7 | 0.0 |
| 99% | 0.0 | 0.0 | 39.7 | 0.0 | 39.7 | 0.0 |
| 98% | 0.0 | 0.0 | 39.7 | 0.0 | 39.7 | 0.0 |
| 95% | 6.7 | 6.7 | 39.7 | 0.0 | 39.7 | 0.0 |
| 90% | 23.1 | 23.1 | 39.7 | 0.0 | 39.7 | 0.0 |
| 85% | 36.3 | 36.3 | 39.7 | 0.0 | 39.7 | 0.0 |
| 80% | 50.3 | 50.3 | 39.7 | 0.0 | 39.7 | 0.0 |
| 75% | 65.5 | 65.5 | 55.5 | 0.0 | 55.5 | 0.0 |
| 70% | 84.0 | 84.0 | 61.5 | 0.0 | 61.5 | 0.0 |
| 60% | 131.1 | 131.1 | 61.5 | 0.0 | 61.5 | 0.0 |
| 50% | 184.5 | 184.5 | 79.3 | 0.0 | 79.3 | 0.0 |
| 40% | 256.6 | 256.6 | 83.3 | 0.0 | 83.3 | 0.0 |
| 30% | 356.3 | 356.3 | 83.3 | 0.0 | 83.3 | 0.0 |
| 25% | 425.6 | 425.6 | 83.3 | 0.0 | 83.3 | 0.0 |
| 20% | 516.1 | 516.1 | 123.0 | 0.0 | 123.0 | 0.0 |
| 15% | 650.0 | 650.0 | 123.0 | 5.4 | 123.0 | 5.4 |
| 10% | 854.2 | 854.2 | 123.0 | 17.9 | 123.0 | 17.9 |
| 5% | 1,312 | 1,312 | 123.0 | 34.2 | 123.0 | 34.2 |
| 2% | 2,172 | 2,172 | 123.0 | 39.7 | 638.7 | 39.7 |
| 1% | 3,117 | 3,117 | 123.0 | 39.7 | 694.2 | 39.7 |
| 0.50% | 4,486 | 4,486 | 123.0 | 55.5 | 868.8 | 55.5 |
| Maximum | 31,932 | 31,932 | 123.0 | 55.5 | 1,375 | 55.5 |

Table 7.27 presents the flow frequency metrics at control point SRRLE. There are different statistic parameters and flow frequencies between the naturalized and regulated flows at the control point. Environmental flows are engaged as 785.5 acre-feet/day in minimum, and 6,704 acre-feet/day in maximum.

Table 7.27 Flow Frequency Metrics (acre-feet/day) for Control Point SRRLE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 17,153 | 11,000 | 1,918 | 95.0 | 2,045 | 95.0 |
| Stan Dev | 19,677 | 16,777 | 922 | 278.5 | 1,154 | 278.5 |
| Minimum | 120.1 | 0.0 | 785.5 | 0.0 | 785.5 | 0.0 |
| 99.50% | 359.5 | 0.0 | 785.5 | 0.0 | 785.5 | 0.0 |
| 99% | 491.6 | 0.0 | 785.5 | 0.0 | 785.5 | 0.0 |
| 98% | 645.9 | 0.0 | 785.5 | 0.0 | 785.5 | 0.0 |
| 95% | 1,068 | 206.7 | 785.5 | 0.0 | 785.5 | 0.0 |
| 90% | 1,723 | 441.8 | 785.5 | 0.0 | 785.5 | 0.0 |
| 85% | 2,299 | 766.1 | 785.5 | 0.0 | 785.5 | 0.0 |
| 80% | 2,958 | 1,111 | 864.8 | 0.0 | 864.8 | 0.0 |
| 75% | 3,723 | 1,459 | 864.8 | 0.0 | 864.8 | 0.0 |
| 70% | 4,556 | 1,792 | 1,462 | 0.0 | 1,462 | 0.0 |
| 60% | 6,764 | 2,737 | 1,605 | 0.0 | 1,605 | 0.0 |
| 50% | 9,798 | 4,066 | 1,605 | 0.0 | 1,605 | 0.0 |
| 40% | 14,324 | 6,207 | 2,636 | 0.0 | 2,636 | 0.0 |
| 30% | 20,609 | 10,342 | 2,636 | 0.0 | 2,636 | 0.0 |
| 25% | 24,337 | 13,414 | 2,636 | 0.0 | 2,636 | 0.0 |
| 20% | 28,975 | 17,770 | 3,316 | 0.0 | 3,316 | 0.0 |
| 15% | 34,545 | 23,679 | 3,316 | 101 | 3,316 | 101 |
| 10% | 41,968 | 31,665 | 3,316 | 417 | 3,316 | 417 |
| 5% | 54,257 | 44,148 | 3,316 | 668 | 3,316 | 668 |
| 2% | 73,701 | 61,468 | 3,316 | 865 | 6,223 | 865 |
| 1% | 90,381 | 79,070 | 3,316 | 1,656 | 6,446 | 1,656 |
| 0.50% | 106,170 | 92,610 | 3,316 | 1,882 | 6,667 | 1,882 |
| Maximum | 278,369 | 254,852 | 3,316 | 1,882 | 6,704 | 1,882 |

### 7.3.2 Neches WAM

The SIMD and TABLES programs of the WRAP modeling system are applied with the Neches WAM to develop four different daily flow sequences and their flow frequency metrics, respectively at the five control points, listed in Table 6.3. The simulation covers the 1940-2013 period-of-analysis, and a full authorized use scenario is adopted.

Table 7.28 presents the flow frequency metrics for naturalized flow, regulated flow, SB3 environmental flow target and shortage in meeting the SB3 environmental target at the control point NENEE. There is the significant difference between the mean values of the naturalized and regulated flows at the control points. This is attributed to the flow control of Palestine Lake and water uses. The minimum shortage of the environmental flow target occurs at 10 % of the exceedance frequency.

Table 7.28 Flow Frequency Metrics (acre-feet/day) for Control Point NENEE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 1,509 | 822.0 | 137.5 | 4.7 | 197.6 | 4.7 |
| Stan Dev | 2,754 | 1,900 | 114.6 | 16.2 | 295.9 | 16.2 |
| Minimum | 0.0 | 0.0 | 23.8 | 0.0 | 23.8 | 0.0 |
| 99.50% | 0.0 | 0.0 | 23.8 | 0.0 | 23.8 | 0.0 |
| 99% | 0.0 | 0.0 | 23.8 | 0.0 | 23.8 | 0.0 |
| 98% | 0.0 | 0.0 | 23.8 | 0.0 | 23.8 | 0.0 |
| 95% | 0.0 | 17.1 | 23.8 | 0.0 | 23.8 | 0.0 |
| 90% | 11.0 | 45.0 | 25.8 | 0.0 | 25.8 | 0.0 |
| 85% | 40.6 | 55.5 | 25.8 | 0.0 | 25.8 | 0.0 |
| 80% | 78.2 | 65.4 | 25.8 | 0.0 | 25.8 | 0.0 |
| 75% | 125.2 | 79.8 | 41.7 | 0.0 | 41.7 | 0.0 |
| 70% | 175.1 | 87.6 | 41.7 | 0.0 | 41.7 | 0.0 |
| 60% | 313.6 | 106.7 | 91.2 | 0.0 | 91.2 | 0.0 |
| 50% | 520.6 | 180.8 | 101.2 | 0.0 | 101.2 | 0.0 |
| 40% | 823.5 | 307.5 | 158.7 | 0.0 | 158.7 | 0.0 |
| 30% | 1,291 | 525.3 | 190.4 | 0.0 | 190.4 | 0.0 |
| 25% | 1,644 | 679.8 | 190.4 | 0.0 | 190.4 | 0.0 |
| 20% | 2,163 | 935.4 | 190.4 | 0.0 | 190.4 | 0.0 |
| 15% | 2,900 | 1,339 | 388.8 | 0.0 | 388.8 | 0.0 |
| 10% | 4,094 | 2,093 | 388.8 | 9.0 | 388.8 | 9.0 |
| 5% | 6,443 | 3,847 | 388.8 | 45.5 | 684.3 | 45.5 |
| 2% | 10,063 | 6,930 | 388.8 | 67.8 | 1,626 | 67.8 |
| 1% | 12,508 | 9,403 | 388.8 | 98.5 | 1,626 | 98.5 |
| 0.50% | 16,534 | 11,604 | 388.8 | 101.2 | 1,652 | 101.2 |
| Maximum | 52,115 | 50,281 | 388.8 | 101.2 | 1,652 | 101.2 |

The regulated flow decreases slightly compared to the naturalized flow at the control point NEROE, as shown in Table 7.29. The shortage of the environmental flow target is 7.0 acre-feet/day in average, and 132.9 acre-feet/day in maximum at the control point.

Table 7.29 Flow Frequency Metrics (acre-feet/day) for Control Point NEROE

| | Naturalized Flow | Regulated Flow | Subsidence and Base | | Total Including Pulse | |
|---|---|---|---|---|---|---|
| | | | IF Target | IF Shortage | IF Target | IF Shortage |
| Mean | 4,809 | 4,021 | 453.3 | 7.0 | 641.5 | 7.0 |
| Stan Dev | 7,262 | 6,677 | 455.4 | 20.7 | 998.6 | 20.7 |
| Minimum | 0.0 | 0.0 | 41.7 | 0.0 | 41.7 | 0.0 |
| 99.50% | 0.0 | 0.0 | 41.7 | 0.0 | 41.7 | 0.0 |
| 99% | 0.0 | 0.0 | 41.7 | 0.0 | 41.7 | 0.0 |
| 98% | 0.0 | 0.0 | 41.7 | 0.0 | 41.7 | 0.0 |
| 95% | 37.9 | 0.2 | 41.7 | 0.0 | 41.7 | 0.0 |
| 90% | 122.7 | 0.9 | 41.7 | 0.0 | 41.7 | 0.0 |
| 85% | 231.8 | 58.0 | 41.7 | 0.0 | 41.7 | 0.0 |
| 80% | 363.7 | 133.0 | 57.5 | 0.0 | 57.5 | 0.0 |
| 75% | 519.0 | 235.0 | 132.9 | 0.0 | 132.9 | 0.0 |
| 70% | 695.0 | 362.0 | 132.9 | 0.0 | 132.9 | 0.0 |
| 60% | 1,213 | 738.9 | 132.9 | 0.0 | 132.9 | 0.0 |
| 50% | 2,039 | 1,370 | 178.5 | 0.0 | 178.5 | 0.0 |
| 40% | 3,189 | 2,347 | 386.8 | 0.0 | 386.8 | 0.0 |
| 30% | 4,877 | 3,841 | 833.1 | 0.0 | 833.1 | 0.0 |
| 25% | 6,124 | 4,958 | 833.1 | 0.0 | 833.1 | 0.0 |
| 20% | 7,693 | 6,422 | 1,196 | 0.0 | 1,196 | 0.0 |
| 15% | 9,916 | 8,399 | 1,196 | 0.0 | 1,196 | 0.0 |
| 10% | 12,767 | 11,337 | 1,196 | 40.8 | 1,196 | 40.8 |
| 5% | 18,859 | 16,861 | 1,196 | 41.7 | 2,318 | 41.7 |
| 2% | 27,297 | 24,583 | 1,196 | 57.0 | 3,969 | 57.0 |
| 1% | 33,726 | 30,890 | 1,196 | 132.6 | 6,109 | 132.6 |
| 0.50% | 42,461 | 39,342 | 1,196 | 132.8 | 6,109 | 132.8 |
| Maximum | 100,881 | 98,545 | 1,196 | 132.9 | 6,109 | 132.9 |

The regulated flow has slightly different statistic parameters and flow frequency metrics from the naturalized flow at the control point ANALE due to water uses and flow controls by the Tyler East and Tyler dams, as listed in Table 7.30. The regulated flow can meet the environmental flow target engaged by the WRAP model for 90% of the period-of-analysis at the control point.

Table 7.30 Flow Frequency Metrics (acre-feet/day) for Control Point ANALE

| | Naturalized Flow | Regulated Flow | Subsidence and Base IF Target | Subsidence and Base IF Shortage | Total Including Pulse IF Target | Total Including Pulse IF Shortage |
|---|---|---|---|---|---|---|
| Mean | 1,874 | 1,420 | 170.8 | 3.1 | 276.6 | 3.1 |
| Stan Dev | 3,232 | 2,739 | 179.8 | 11.0 | 492.2 | 11.0 |
| Minimum | 0.0 | 0.0 | 21.8 | 0.0 | 21.8 | 0.0 |
| 99.50% | 0.0 | 0.0 | 21.8 | 0.0 | 21.8 | 0.0 |
| 99% | 0.0 | 0.0 | 21.8 | 0.0 | 21.8 | 0.0 |
| 98% | 1.8 | 0.0 | 21.8 | 0.0 | 21.8 | 0.0 |
| 95% | 15.3 | 0.0 | 21.8 | 0.0 | 21.8 | 0.0 |
| 90% | 41.6 | 18.8 | 21.8 | 0.0 | 21.8 | 0.0 |
| 85% | 72.2 | 40.3 | 31.7 | 0.0 | 31.7 | 0.0 |
| 80% | 111.1 | 61.0 | 35.7 | 0.0 | 35.7 | 0.0 |
| 75% | 159.4 | 86.5 | 35.7 | 0.0 | 35.7 | 0.0 |
| 70% | 216.2 | 119.4 | 79.3 | 0.0 | 79.3 | 0.0 |
| 60% | 363.1 | 208.7 | 103.1 | 0.0 | 103.1 | 0.0 |
| 50% | 608.4 | 363.2 | 103.1 | 0.0 | 103.1 | 0.0 |
| 40% | 1,010 | 630.9 | 109.1 | 0.0 | 109.1 | 0.0 |
| 30% | 1,667 | 1,102 | 178.5 | 0.0 | 178.5 | 0.0 |
| 25% | 2,153 | 1,467 | 178.5 | 0.0 | 178.5 | 0.0 |
| 20% | 2,803 | 1,987 | 549.4 | 0.0 | 549.4 | 0.0 |
| 15% | 3,733 | 2,787 | 549.4 | 0.0 | 549.4 | 0.0 |
| 10% | 5,213 | 4,004 | 549.4 | 10.7 | 549.4 | 10.7 |
| 5% | 8,097 | 6,541 | 549.4 | 21.8 | 1,166 | 21.8 |
| 2% | 12,055 | 10,340 | 549.4 | 35.2 | 2,182 | 35.2 |
| 1% | 15,226 | 13,092 | 549.4 | 35.7 | 3,213 | 35.7 |
| 0.50% | 18,479 | 16,459 | 549.4 | 90.1 | 3,213 | 90.1 |
| Maximum | 55,090 | 54,732 | 549.4 | 109.1 | 3,213 | 109.1 |

Table 7.31 presents the flow frequency metrics at control point NEEVE. There are considerably different statistic parameters and flow frequencies between the naturalized and regulated flows at the control point. The minimum shortage of the environmental flow target occurs at 25% of exceedance frequency.

Table 7.31 Flow Frequency Metrics (acre-feet/day) for Control Point NEEVE

| | | | Subsidence and Base | | Total Including Pulse | |
|---|---|---|---|---|---|---|
| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage | IF Target | IF Shortage |
| Mean | 12,349 | 8,511 | 1,551 | 101.7 | 1,675 | 101.7 |
| Stan Dev | 16,977 | 14,378 | 1,409 | 290.3 | 1,622 | 290.3 |
| Minimum | 0.0 | 0.0 | 452.2 | 0.0 | 452.2 | 0.0 |
| 99.50% | 31.3 | 0.0 | 452.2 | 0.0 | 452.2 | 0.0 |
| 99% | 64.3 | 0.0 | 452.2 | 0.0 | 452.2 | 0.0 |
| 98% | 107.7 | 0.0 | 452.2 | 0.0 | 452.2 | 0.0 |
| 95% | 185.5 | 0.5 | 452.2 | 0.0 | 452.2 | 0.0 |
| 90% | 392.9 | 0.9 | 452.2 | 0.0 | 452.2 | 0.0 |
| 85% | 675.8 | 119.0 | 452.2 | 0.0 | 452.2 | 0.0 |
| 80% | 1,121 | 246.7 | 452.2 | 0.0 | 452.2 | 0.0 |
| 75% | 1,599 | 414.2 | 452.2 | 0.0 | 452.2 | 0.0 |
| 70% | 2,148 | 605.2 | 452.2 | 0.0 | 452.2 | 0.0 |
| 60% | 3,671 | 1,102 | 527.6 | 0.0 | 527.6 | 0.0 |
| 50% | 5,711 | 1,792 | 1,016 | 0.0 | 1,016 | 0.0 |
| 40% | 8,873 | 3,440 | 1,150 | 0.0 | 1,150 | 0.0 |
| 30% | 13,561 | 7,406 | 3,114 | 0.0 | 3,114 | 0.0 |
| 25% | 16,417 | 10,121 | 3,578 | 52.2 | 3,578 | 52.2 |
| 20% | 20,341 | 13,614 | 3,578 | 218.3 | 3,578 | 218.3 |
| 15% | 25,663 | 18,570 | 3,818 | 339.6 | 3,818 | 339.6 |
| 10% | 33,442 | 27,967 | 3,818 | 451.3 | 3,818 | 451.3 |
| 5% | 45,905 | 40,591 | 3,818 | 452.2 | 3,818 | 452.2 |
| 2% | 63,594 | 58,140 | 3,818 | 527.1 | 5,392 | 527.1 |
| 1% | 77,558 | 65,429 | 3,818 | 527.3 | 7,597 | 527.3 |
| 0.50% | 91,127 | 70,820 | 3,818 | 1,015.5 | 7,597 | 1,015.5 |
| Maximum | 274,941 | 196,728 | 3,818 | 7,596.7 | 7,597 | 7,596.7 |

Both naturalized and regulated flows have nearly identical flow frequency metrics in the control point VIKOE, as presented in Table 7.32. This means that there are no water uses and flow controllers upstream of the control point. The exceedance frequency that the environmental flow shortage occurs is below 15%.

Table 7.32 Flow Frequency Metrics (acre-feet/day) for Control Point VIKOE

| | | | Subsidence and Base | | Total Including Pulse | |
|---|---|---|---|---|---|---|
| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage | IF Target | IF Shortage |
| Mean | 1,749 | 1,748 | 219.3 | 13.7 | 347.8 | 13.7 |
| Stan Dev | 3,396 | 3,396 | 147.3 | 30.7 | 576.2 | 30.7 |
| Minimum | 0.0 | 0.0 | 81.3 | 0.0 | 81.3 | 0.0 |
| 99.50% | 0.0 | 0.0 | 81.3 | 0.0 | 81.3 | 0.0 |
| 99% | 0.0 | 0.0 | 81.3 | 0.0 | 81.3 | 0.0 |
| 98% | 0.0 | 0.0 | 81.3 | 0.0 | 81.3 | 0.0 |
| 95% | 2.8 | 2.7 | 81.3 | 0.0 | 81.3 | 0.0 |
| 90% | 23.2 | 23.0 | 81.3 | 0.0 | 81.3 | 0.0 |
| 85% | 50.4 | 49.9 | 81.3 | 0.0 | 81.3 | 0.0 |
| 80% | 81.2 | 80.6 | 97.2 | 0.0 | 97.2 | 0.0 |
| 75% | 124.9 | 124.3 | 97.2 | 0.0 | 97.2 | 0.0 |
| 70% | 174.5 | 173.4 | 152.7 | 0.0 | 152.7 | 0.0 |
| 60% | 313.6 | 312.8 | 152.7 | 0.0 | 152.7 | 0.0 |
| 50% | 537.5 | 536.2 | 194.4 | 0.0 | 194.4 | 0.0 |
| 40% | 864.2 | 863.0 | 194.4 | 0.0 | 194.4 | 0.0 |
| 30% | 1,397 | 1,395 | 232.1 | 0.0 | 232.1 | 0.0 |
| 25% | 1,824 | 1,822 | 232.1 | 0.0 | 232.1 | 0.0 |
| 20% | 2,447 | 2,445 | 523.6 | 13.5 | 523.6 | 13.5 |
| 15% | 3,304 | 3,300 | 523.6 | 44.6 | 523.6 | 44.6 |
| 10% | 4,798 | 4,798 | 523.6 | 70.4 | 523.6 | 70.4 |
| 5% | 7,743 | 7,743 | 523.6 | 81.3 | 1,412 | 81.3 |
| 2% | 11,529 | 11,528 | 523.6 | 97.2 | 2,737 | 97.2 |
| 1% | 15,968 | 15,966 | 523.6 | 135.3 | 3,987 | 135.3 |
| 0.50% | 21,698 | 21,673 | 523.6 | 153.5 | 3,987 | 153.5 |
| Maximum | 64,692 | 64,700 | 523.6 | 164.6 | 3,987 | 164.6 |

### 7.3.3 GSA WAM

The WRAP model for the GSA WAM computes the regulated flows based on naturalized datasets and engages the environmental flow target based on the regulated flow and hydrologic index (HIS file) at 15 control points. Flow frequency metrics are developed as presented in Tables 7.33 to 7.47. The simulation covers the period-of-analysis (1934-2013), and a full authorized use scenario is adopted.

Table 7.33 Flow Frequency Metrics (acre-feet/day) for Control Point CP01E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 412.4 | 382.1 | 136.2 | 6.9 |
| Stan Dev | 1,585 | 1,568 | 164.7 | 15.3 |
| Minimum | 0.0 | 0.0 | 4.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 4.0 | 0.0 |
| 99% | 0.0 | 0.0 | 4.0 | 0.0 |
| 98% | 0.3 | 0.1 | 4.0 | 0.0 |
| 95% | 1.5 | 0.4 | 4.4 | 0.0 |
| 90% | 5.7 | 2.8 | 23.1 | 0.0 |
| 85% | 12.2 | 8.1 | 35.7 | 0.0 |
| 80% | 23.0 | 16.9 | 40.4 | 0.0 |
| 75% | 36.3 | 29.7 | 49.6 | 0.0 |
| 70% | 54.2 | 46.3 | 54.7 | 0.0 |
| 60% | 101.6 | 89.7 | 63.3 | 0.0 |
| 50% | 164.3 | 141.6 | 96.0 | 0.0 |
| 40% | 246.9 | 210.0 | 148.8 | 0.0 |
| 30% | 367.5 | 319.9 | 198.3 | 0.0 |
| 25% | 446.7 | 392.7 | 198.3 | 0.1 |
| 20% | 545.6 | 491.9 | 218.2 | 3.9 |
| 15% | 687.5 | 626.7 | 218.2 | 22.5 |
| 10% | 914.0 | 850.0 | 218.2 | 34.7 |
| 5% | 1,381 | 1,313 | 277.7 | 46.3 |
| 2% | 2,255 | 2,180 | 694.2 | 58.1 |
| 1% | 3,335 | 3,226 | 793.4 | 60.9 |
| 0.50% | 5,186 | 5,098 | 991.7 | 61.3 |
| Maximum | 182,609 | 181,764 | 2,360 | 61.5 |

The regulated flows have almost similar statistical parameters but slightly different flow frequency metrics at the 10 control points CP01E, CP02E, CP08E, CP10E, CP11E, C38461E, CP14E, and CP15 in the Guadalupe River Basin. The major water rights in the Guadalupe River Basin are hydroelectric generations. The flows, utilized for generating electricity, must fully return to the river without losses. For these reasons, the amounts of both flows are almost similar, but flow timing and regime are changed slightly.

Table 7.34 Flow Frequency Metrics (acre-feet/day) for Control Point CP02E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 709.0 | 681.4 | 218.1 | 4.2 |
| Stan Dev | 1,895 | 1,878 | 300.4 | 10.4 |
| Minimum | 0.0 | 0.0 | 35.7 | 0.0 |
| 99.50% | 0.0 | 0.0 | 35.7 | 0.0 |
| 99% | 0.0 | 0.0 | 35.7 | 0.0 |
| 98% | 0.0 | 0.0 | 35.7 | 0.0 |
| 95% | 2.2 | 0.9 | 35.7 | 0.0 |
| 90% | 14.0 | 11.1 | 35.7 | 0.0 |
| 85% | 33.9 | 29.0 | 35.7 | 0.0 |
| 80% | 57.9 | 52.0 | 43.9 | 0.0 |
| 75% | 85.0 | 78.4 | 57.1 | 0.0 |
| 70% | 118.8 | 109.0 | 72.5 | 0.0 |
| 60% | 197.3 | 183.0 | 109.6 | 0.0 |
| 50% | 298.1 | 276.1 | 168.6 | 0.0 |
| 40% | 443.2 | 411.2 | 218.2 | 0.0 |
| 30% | 654.7 | 614.4 | 297.5 | 0.0 |
| 25% | 789.7 | 744.3 | 317.4 | 0.0 |
| 20% | 968.5 | 914.8 | 317.4 | 0.0 |
| 15% | 1,208 | 1,156 | 317.4 | 6.7 |
| 10% | 1,592 | 1,536 | 317.4 | 24.6 |
| 5% | 2,444 | 2,382 | 416.5 | 34.8 |
| 2% | 4,012 | 3,930 | 1,072 | 35.7 |
| 1% | 5,975 | 5,846 | 1,726 | 35.7 |
| 0.50% | 8,721 | 8,681 | 1,726 | 35.7 |
| Maximum | 164,943 | 164,498 | 4,582 | 35.7 |

Table 7.35 Flow Frequency Metrics (acre-feet/day) for Control Point CP08E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 280.8 | 278.1 | 86.5 | 1.7 |
| Stan Dev | 806.7 | 802.8 | 124.6 | 4.8 |
| Minimum | 0.0 | 0.0 | 15.9 | 0.0 |
| 99.50% | 0.0 | 0.0 | 15.9 | 0.0 |
| 99% | 0.0 | 0.0 | 15.9 | 0.0 |
| 98% | 0.0 | 0.0 | 15.9 | 0.0 |
| 95% | 5.8 | 5.4 | 18.2 | 0.0 |
| 90% | 12.6 | 12.3 | 19.8 | 0.0 |
| 85% | 19.3 | 18.8 | 21.1 | 0.0 |
| 80% | 26.6 | 25.9 | 25.8 | 0.0 |
| 75% | 35.2 | 34.3 | 27.2 | 0.0 |
| 70% | 44.9 | 44.0 | 32.0 | 0.0 |
| 60% | 67.7 | 66.2 | 43.3 | 0.0 |
| 50% | 99.9 | 98.4 | 59.5 | 0.0 |
| 40% | 148.3 | 145.4 | 103.1 | 0.0 |
| 30% | 225.8 | 223.1 | 111.1 | 0.0 |
| 25% | 284.4 | 280.6 | 126.9 | 0.0 |
| 20% | 366.1 | 361.7 | 126.9 | 0.0 |
| 15% | 474.6 | 470.0 | 126.9 | 0.9 |
| 10% | 662.6 | 656.1 | 126.9 | 7.5 |
| 5% | 1,043 | 1,036 | 126.9 | 14.8 |
| 2% | 1,736 | 1,733 | 376.9 | 19.7 |
| 1% | 2,611 | 2,608 | 714.0 | 21.9 |
| 0.50% | 3,510 | 3,468 | 753.7 | 25.8 |
| Maximum | 73,319 | 73,029 | 1,904 | 25.8 |

The variances of both naturalized and regulated flows are bigger than the means at all the control points in the Guadalupe River Basin. That means that the flow variability in the Guadalupe River Basin is much higher than other basins like the Sabine and Neches River Basins in this research. The exceedance frequencies of the environmental flow target shortage at the 9 control points are also relatively higher than two other basins.

Table 7.36 Flow Frequency Metrics (acre-feet/day) for Control Point CP10E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 758.0 | 740.2 | 338.3 | 36.6 |
| Stan Dev | 1,682 | 1,665 | 366.0 | 59.8 |
| Minimum | 0.0 | 0.0 | 144.8 | 0.0 |
| 99.50% | 0.0 | 0.0 | 144.8 | 0.0 |
| 99% | 0.0 | 0.0 | 144.8 | 0.0 |
| 98% | 0.0 | 0.0 | 144.8 | 0.0 |
| 95% | 1.8 | 0.3 | 144.8 | 0.0 |
| 90% | 14.9 | 10.6 | 144.8 | 0.0 |
| 85% | 34.9 | 30.9 | 160.7 | 0.0 |
| 80% | 59.9 | 57.2 | 167.3 | 0.0 |
| 75% | 88.9 | 91.7 | 176.5 | 0.0 |
| 70% | 123.7 | 134.4 | 176.5 | 0.0 |
| 60% | 212.4 | 213.5 | 188.7 | 0.0 |
| 50% | 330.2 | 315.8 | 240.3 | 0.0 |
| 40% | 482.3 | 461.5 | 396.7 | 0.0 |
| 30% | 698.6 | 669.8 | 416.5 | 28.1 |
| 25% | 844.2 | 811.4 | 416.5 | 69.4 |
| 20% | 1,039 | 1,003 | 436.4 | 104.2 |
| 15% | 1,314 | 1,273 | 436.4 | 130.8 |
| 10% | 1,740 | 1,700 | 436.4 | 144.8 |
| 5% | 2,654 | 2,613 | 436.4 | 163.6 |
| 2% | 4,533 | 4,480 | 1,083 | 176.5 |
| 1% | 6,705 | 6,665 | 2,386 | 176.5 |
| 0.50% | 9,937 | 9,863 | 3,317 | 176.5 |
| Maximum | 758.0 | 101,154 | 3,965 | 176.5 |

Table 7.37 Flow Frequency Metrics (acre-feet/day) for Control Point CP11E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 220.4 | 219.1 | 33.0 | 1.0 |
| Stan Dev | 1,140 | 1,136 | 210.6 | 1.6 |
| Minimum | 0.0 | 0.0 | 2.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 2.0 | 0.0 |
| 99% | 0.0 | 0.0 | 2.0 | 0.0 |
| 98% | 0.0 | 0.0 | 2.0 | 0.0 |
| 95% | 0.0 | 0.0 | 2.0 | 0.0 |
| 90% | 0.0 | 0.0 | 2.0 | 0.0 |
| 85% | 0.1 | 0.1 | 2.0 | 0.0 |
| 80% | 0.4 | 0.4 | 2.0 | 0.0 |
| 75% | 0.9 | 0.8 | 3.0 | 0.0 |
| 70% | 1.5 | 1.4 | 4.0 | 0.0 |
| 60% | 3.7 | 3.6 | 5.3 | 0.0 |
| 50% | 8.2 | 8.0 | 6.0 | 0.0 |
| 40% | 17.7 | 17.4 | 9.9 | 0.0 |
| 30% | 41.0 | 40.5 | 15.9 | 1.5 |
| 25% | 63.9 | 63.0 | 15.9 | 1.9 |
| 20% | 106.8 | 105.6 | 19.8 | 2.0 |
| 15% | 193.3 | 191.5 | 19.8 | 2.0 |
| 10% | 388.8 | 384.5 | 23.8 | 3.6 |
| 5% | 978.2 | 973.4 | 23.8 | 4.5 |
| 2% | 2,420 | 2,395 | 297.5 | 5.8 |
| 1% | 4,037 | 4,020 | 694.2 | 6.0 |
| 0.50% | 5,846 | 5,845 | 1,428 | 6.0 |
| Maximum | 72,919 | 72,920 | 4,165 | 6.0 |

Table 7.38 Flow Frequency Metrics (acre-feet/day) for Control Point C38461E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 2,576 | 2,256 | 1,194 | 35.7 |
| Stan Dev | 4,120 | 3,491 | 1,037 | 93.0 |
| Minimum | 0.0 | 0.0 | 357.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 357.0 | 0.0 |
| 99% | 0.0 | 2.4 | 357.0 | 0.0 |
| 98% | 9.8 | 37.2 | 357.0 | 0.0 |
| 95% | 70.2 | 120.7 | 416.5 | 0.0 |
| 90% | 178.4 | 230.3 | 416.5 | 0.0 |
| 85% | 305.8 | 348.2 | 416.5 | 0.0 |
| 80% | 436.3 | 486.8 | 444.7 | 0.0 |
| 75% | 572.8 | 638.3 | 520.7 | 0.0 |
| 70% | 719.7 | 790.9 | 597.7 | 0.0 |
| 60% | 1,056 | 1,137 | 769.5 | 0.0 |
| 50% | 1,454 | 1,499 | 976.9 | 0.0 |
| 40% | 1,934 | 1,671 | 1,480 | 0.0 |
| 30% | 2,569 | 1,724 | 1,480 | 0.0 |
| 25% | 2,992 | 1,757 | 1,569 | 0.0 |
| 20% | 3,537 | 2,311 | 1,569 | 0.0 |
| 15% | 4,324 | 2,877 | 1,579 | 50.9 |
| 10% | 5,658 | 5,303 | 1,579 | 177.8 |
| 5% | 8,646 | 10,435 | 1,884 | 289.4 |
| 2% | 14,079 | 12,339 | 4,384 | 364.6 |
| 1% | 19,289 | 14,186 | 8,212 | 412.3 |
| 0.50% | 24,984 | 18,319 | 8,239 | 416.5 |
| Maximum | 111,820 | 96,140 | 8,239 | 416.5 |

Table 7.39 Flow Frequency Metrics (acre-feet/day) for Control Point CP13E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 260.8 | 259.2 | 30.6 | 0.6 |
| Stan Dev | 1,329 | 1,323 | 131.2 | 1.5 |
| Minimum | 0.0 | 0.0 | 2.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 2.0 | 0.0 |
| 99% | 0.0 | 0.0 | 2.0 | 0.0 |
| 98% | 0.0 | 0.0 | 2.0 | 0.0 |
| 95% | 0.2 | 0.2 | 2.0 | 0.0 |
| 90% | 0.7 | 0.7 | 2.0 | 0.0 |
| 85% | 1.5 | 1.5 | 2.8 | 0.0 |
| 80% | 2.5 | 2.5 | 4.0 | 0.0 |
| 75% | 3.8 | 3.7 | 4.3 | 0.0 |
| 70% | 5.4 | 5.3 | 6.4 | 0.0 |
| 60% | 10.6 | 10.5 | 7.9 | 0.0 |
| 50% | 19.7 | 19.6 | 7.9 | 0.0 |
| 40% | 36.4 | 36.1 | 17.9 | 0.0 |
| 30% | 68.7 | 68.2 | 17.9 | 0.0 |
| 25% | 98.4 | 97.5 | 17.9 | 0.0 |
| 20% | 144.2 | 142.8 | 17.9 | 0.9 |
| 15% | 228.7 | 226.4 | 23.8 | 1.7 |
| 10% | 434.5 | 431.7 | 23.8 | 2.0 |
| 5% | 1,067 | 1,057 | 23.8 | 4.0 |
| 2% | 2,711 | 2,690 | 297.5 | 6.7 |
| 1% | 4,689 | 4,680 | 740.1 | 7.5 |
| 0.50% | 7,392 | 7,316 | 1,131 | 7.8 |
| Maximum | 95,545 | 95,114 | 1,527 | 7.9 |

Table 7.40 Flow Frequency Metrics (acre-feet/day) for Control Point CP14E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 3,390 | 3,105 | 1,378 | 13.6 |
| Stan Dev | 6,179 | 5,468 | 1,470 | 46.1 |
| Minimum | 0.0 | 0.0 | 170.6 | 0.0 |
| 99.50% | 1.1 | 0.0 | 170.6 | 0.0 |
| 99% | 4.1 | 3.9 | 170.6 | 0.0 |
| 98% | 13.3 | 34.2 | 206.2 | 0.0 |
| 95% | 72.6 | 110.9 | 240.1 | 0.0 |
| 90% | 171.5 | 216.5 | 257.9 | 0.0 |
| 85% | 292.7 | 339.3 | 285.8 | 0.0 |
| 80% | 445.2 | 478.7 | 354.0 | 0.0 |
| 75% | 611.3 | 626.7 | 429.0 | 0.0 |
| 70% | 807.6 | 791.4 | 513.2 | 0.0 |
| 60% | 1,217 | 1,472 | 849.2 | 0.0 |
| 50% | 1,692 | 1,947 | 1,587 | 0.0 |
| 40% | 2,236 | 2,219 | 1,726 | 0.0 |
| 30% | 3,045 | 2,317 | 1,865 | 0.0 |
| 25% | 3,628 | 2,581 | 1,865 | 0.0 |
| 20% | 4,424 | 3,167 | 1,865 | 0.0 |
| 15% | 5,572 | 4,693 | 1,944 | 0.0 |
| 10% | 7,691 | 7,366 | 1,944 | 19.9 |
| 5% | 12,309 | 11,837 | 2,083 | 130.7 |
| 2% | 20,480 | 18,491 | 5,172 | 202.7 |
| 1% | 28,272 | 24,955 | 8,232 | 241.6 |
| 0.50% | 39,400 | 33,744 | 10,314 | 257.9 |
| Maximum | 137,129 | 130,576 | 17,593 | 257.9 |

Table 7.41 Flow Frequency Metrics (acre-feet/day) for Control Point CP15EE

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 3,508 | 3,187 | 1,346 | 20.0 |
| Stan Dev | 6,110 | 5,352 | 982.0 | 59.6 |
| Minimum | 0.0 | 0.0 | 218.2 | 0.0 |
| 99.50% | 0.0 | 0.0 | 218.2 | 0.0 |
| 99% | 6.6 | 3.3 | 218.2 | 0.0 |
| 98% | 29.1 | 31.2 | 219.9 | 0.0 |
| 95% | 96.3 | 100.8 | 257.9 | 0.0 |
| 90% | 213.8 | 197.6 | 297.5 | 0.0 |
| 85% | 355.3 | 307.0 | 317.4 | 0.0 |
| 80% | 519.8 | 433.5 | 352.8 | 0.0 |
| 75% | 690.8 | 570.9 | 423.1 | 0.0 |
| 70% | 894.0 | 743.0 | 509.8 | 0.0 |
| 60% | 1,321 | 1,648 | 969.0 | 0.0 |
| 50% | 1,789 | 2,235 | 1,577 | 0.0 |
| 40% | 2,352 | 2,623 | 1,716 | 0.0 |
| 30% | 3,201 | 2,737 | 1,874 | 0.0 |
| 25% | 3,794 | 2,883 | 1,874 | 0.0 |
| 20% | 4,580 | 3,297 | 1,874 | 0.0 |
| 15% | 5,826 | 4,239 | 1,934 | 0.0 |
| 10% | 7,964 | 7,074 | 1,934 | 79.8 |
| 5% | 12,482 | 11,551 | 2,063 | 180.3 |
| 2% | 20,548 | 18,298 | 3,818 | 247.3 |
| 1% | 28,546 | 24,800 | 6,427 | 288.0 |
| 0.50% | 40,964 | 35,504 | 6,427 | 297.5 |
| Maximum | 106,650 | 89,492 | 6,427 | 317.4 |

The regulated flows have almost similar statistical parameters and flow frequency metrics to the naturalized flows at the 2 control points P38241E and CP35E in the San Antonio River Basin. This is because the control point P38241E is located upstream of Medina Lake, and CP35E is located at a tributary.

Table 7.42 Flow Frequency Metrics (acre-feet/day) for Control Point P38241E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 210.7 | 210.4 | 62.9 | 9.5 |
| Stan Dev | 839.5 | 837.3 | 69.3 | 19.7 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.2 | 0.2 | 2.0 | 0.0 |
| 99% | 0.6 | 0.6 | 2.2 | 0.0 |
| 98% | 1.4 | 1.4 | 3.7 | 0.0 |
| 95% | 3.7 | 3.7 | 7.3 | 0.0 |
| 90% | 9.1 | 9.1 | 11.9 | 0.0 |
| 85% | 15.5 | 15.5 | 19.8 | 0.0 |
| 80% | 22.1 | 22.1 | 31.7 | 0.0 |
| 75% | 28.7 | 28.7 | 31.7 | 0.0 |
| 70% | 35.4 | 35.4 | 31.7 | 0.0 |
| 60% | 51.4 | 51.4 | 43.6 | 0.0 |
| 50% | 73.0 | 72.9 | 63.5 | 0.0 |
| 40% | 104.2 | 104.1 | 63.5 | 0.0 |
| 30% | 150.1 | 150.0 | 65.5 | 1.8 |
| 25% | 182.6 | 182.6 | 81.3 | 8.0 |
| 20% | 224.6 | 224.4 | 95.2 | 15.8 |
| 15% | 286.9 | 286.4 | 97.2 | 26.2 |
| 10% | 400.7 | 400.3 | 105.1 | 38.1 |
| 5% | 640.2 | 639.5 | 107.1 | 58.5 |
| 2% | 1,200 | 1,199 | 218.2 | 75.7 |
| 1% | 2,192 | 2,188 | 243.5 | 85.0 |
| 0.50% | 3,934 | 3,934 | 603.2 | 91.1 |
| Maximum | 47,589 | 47,109 | 952.1 | 107.1 |

The regulated flows have considerably different statistical parameters and flow frequency metrics from the naturalized flows at the control points, CP28E, CP29E, CP32E, and CP37E due to water uses and flow controls by Medina Lake in the San Antonio River.

Table 7.43 Flow Frequency Metrics (acre-feet/day) for Control Point CP28E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 505.7 | 308.0 | 125.9 | 17.6 |
| Stan Dev | 1,379 | 1,030 | 130.1 | 31.2 |
| Minimum | 1.2 | 0.0 | 0.0 | 0.0 |
| 99.50% | 4.1 | 0.0 | 15.9 | 0.0 |
| 99% | 7.0 | 2.1 | 15.9 | 0.0 |
| 98% | 10.5 | 7.3 | 20.7 | 0.0 |
| 95% | 18.1 | 16.5 | 25.8 | 0.0 |
| 90% | 35.2 | 28.9 | 32.8 | 0.0 |
| 85% | 55.1 | 39.5 | 39.7 | 0.0 |
| 80% | 74.2 | 49.9 | 65.5 | 0.0 |
| 75% | 94.4 | 59.4 | 105.1 | 0.0 |
| 70% | 114.9 | 72.3 | 105.1 | 0.0 |
| 60% | 160.2 | 96.9 | 113.1 | 0.0 |
| 50% | 207.6 | 122.8 | 119.0 | 0.0 |
| 40% | 271.7 | 154.2 | 123.0 | 0.0 |
| 30% | 374.5 | 195.9 | 123.0 | 12.4 |
| 25% | 445.2 | 230.7 | 140.8 | 23.3 |
| 20% | 549.6 | 283.7 | 142.8 | 37.1 |
| 15% | 708.8 | 364.1 | 146.8 | 53.9 |
| 10% | 986.0 | 533.4 | 152.7 | 70.2 |
| 5% | 1,656 | 975.2 | 234.9 | 90.4 |
| 2% | 3,357 | 2,100 | 494.3 | 110.0 |
| 1% | 5,578 | 3,714 | 753.7 | 120.9 |
| 0.50% | 8,408 | 5,932 | 892.6 | 131.5 |
| Maximum | 45,662 | 44,078 | 1,984 | 152.7 |

The variances of both naturalized and regulated flows are also greater than the means at all the 6 control points in the San Antonio River Basin. That means that the flow variability in the San Antonio River Basin is higher than 2 other basins like the Guadalupe River Basin. The exceedance frequencies of the environmental flow target shortage at the 6 control points are also relatively higher than two other basins as well.

Table 7.44 Flow Frequency Metrics (acre-feet/day) for Control Point CP29E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 770.5 | 487.9 | 473.5 | 230.3 |
| Stan Dev | 2,003 | 1,721 | 526.5 | 204.0 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 119.0 | 0.0 |
| 99% | 0.0 | 0.0 | 119.0 | 0.0 |
| 98% | 0.0 | 0.0 | 119.0 | 0.0 |
| 95% | 1.1 | 1.9 | 119.0 | 0.0 |
| 90% | 27.6 | 8.8 | 119.0 | 0.0 |
| 85% | 60.9 | 17.7 | 119.0 | 0.0 |
| 80% | 92.4 | 26.4 | 160.4 | 0.0 |
| 75% | 122.9 | 33.3 | 228.1 | 22.7 |
| 70% | 154.1 | 46.6 | 353.1 | 74.6 |
| 60% | 232.1 | 90.6 | 442.3 | 116.8 |
| 50% | 325.9 | 144.4 | 470.1 | 192.2 |
| 40% | 445.6 | 214.6 | 470.1 | 300.2 |
| 30% | 611.9 | 303.6 | 519.7 | 350.8 |
| 25% | 724.6 | 366.8 | 650.6 | 389.1 |
| 20% | 881.6 | 459.0 | 650.6 | 426.4 |
| 15% | 1,115 | 608.6 | 676.4 | 461.3 |
| 10% | 1,505 | 891.7 | 722.0 | 514.8 |
| 5% | 2,542 | 1,690 | 727.9 | 616.3 |
| 2% | 5,212 | 3,819 | 727.9 | 658.8 |
| 1% | 8,587 | 6,820 | 2,003 | 695.9 |
| 0.50% | 13,114 | 10,502 | 3,666 | 709.6 |
| Maximum | 57,202 | 56,177 | 7,934 | 726.1 |

Table 7.45 Flow Frequency Metrics (acre-feet/day) for Control Point CP32E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 905.4 | 618.4 | 546.7 | 218.0 |
| Stan Dev | 1,822 | 1,489 | 554.8 | 240.4 |
| Minimum | 0.0 | 2.2 | 0.0 | 0.0 |
| 99.50% | 9.0 | 2.3 | 119.0 | 0.0 |
| 99% | 14.4 | 6.0 | 119.0 | 0.0 |
| 98% | 25.3 | 19.7 | 119.0 | 0.0 |
| 95% | 49.4 | 35.9 | 119.0 | 0.0 |
| 90% | 85.0 | 54.8 | 119.0 | 0.0 |
| 85% | 121.8 | 73.7 | 135.2 | 0.0 |
| 80% | 157.3 | 95.4 | 224.1 | 0.0 |
| 75% | 191.8 | 118.2 | 301.5 | 0.0 |
| 70% | 230.6 | 141.9 | 394.7 | 0.0 |
| 60% | 321.8 | 192.6 | 487.9 | 55.8 |
| 50% | 432.5 | 249.3 | 523.6 | 116.7 |
| 40% | 569.3 | 328.7 | 523.6 | 246.5 |
| 30% | 763.2 | 445.1 | 579.2 | 330.8 |
| 25% | 900.2 | 530.0 | 841.0 | 369.2 |
| 20% | 1,091 | 657.4 | 841.0 | 425.8 |
| 15% | 1,384 | 877.4 | 852.9 | 487.8 |
| 10% | 1,868 | 1,263 | 926.3 | 599.3 |
| 5% | 3,104 | 2,244 | 950.1 | 719.2 |
| 2% | 5,771 | 4,458 | 950.1 | 797.8 |
| 1% | 8,767 | 6,811 | 1,686 | 843.7 |
| 0.50% | 12,329 | 9,593 | 3,015 | 868.1 |
| Maximum | 47,547 | 45,832 | 12,893 | 915.1 |

Table 7.46 Flow Frequency Metrics (acre-feet/day) for Control Point CP35E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 254.4 | 250.2 | 70.4 | 12.6 |
| Stan Dev | 861.7 | 860.2 | 212.0 | 19.4 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 15.9 | 0.0 |
| 99% | 0.0 | 0.0 | 15.9 | 0.0 |
| 98% | 2.1 | 0.8 | 15.9 | 0.0 |
| 95% | 5.3 | 3.9 | 15.9 | 0.0 |
| 90% | 9.6 | 8.3 | 17.3 | 0.0 |
| 85% | 13.4 | 12.2 | 22.2 | 0.0 |
| 80% | 17.5 | 16.1 | 31.7 | 0.0 |
| 75% | 22.4 | 20.7 | 39.7 | 0.0 |
| 70% | 27.5 | 25.4 | 39.7 | 0.0 |
| 60% | 40.1 | 37.7 | 47.6 | 0.0 |
| 50% | 57.0 | 53.1 | 55.5 | 0.0 |
| 40% | 81.8 | 76.9 | 55.5 | 5.1 |
| 30% | 124.0 | 118.2 | 55.5 | 15.1 |
| 25% | 159.9 | 153.4 | 73.4 | 21.7 |
| 20% | 218.0 | 211.5 | 77.4 | 28.8 |
| 15% | 309.7 | 302.7 | 77.4 | 35.2 |
| 10% | 500.4 | 492.0 | 79.3 | 42.4 |
| 5% | 1,024 | 1,016 | 87.3 | 55.5 |
| 2% | 2,228 | 2,214 | 87.3 | 69.0 |
| 1% | 3,714 | 3,701 | 621.8 | 74.6 |
| 0.50% | 5,407 | 5,380 | 1,984 | 78.2 |
| Maximum | 33,996 | 33,990 | 4,959 | 86.0 |

Table 7.47 Flow Frequency Metrics (acre-feet/day) for Control Point CP37E

| | Naturalized Flow | Regulated Flow | IF Target | IF Shortage |
|---|---|---|---|---|
| Mean | 1,433 | 1,159 | 671.7 | 183.0 |
| Stan Dev | 3,102 | 2,848 | 778.0 | 250.4 |
| Minimum | 4.6 | 0.0 | 0.0 | 0.0 |
| 99.50% | 17.1 | 11.6 | 119.0 | 0.0 |
| 99% | 32.2 | 25.5 | 119.0 | 0.0 |
| 98% | 44.3 | 31.3 | 119.0 | 0.0 |
| 95% | 77.1 | 57.7 | 119.0 | 0.0 |
| 90% | 128.8 | 95.7 | 143.8 | 0.0 |
| 85% | 176.4 | 131.0 | 217.5 | 0.0 |
| 80% | 225.9 | 169.9 | 331.2 | 0.0 |
| 75% | 283.3 | 208.1 | 396.7 | 0.0 |
| 70% | 347.6 | 247.6 | 470.1 | 0.0 |
| 60% | 482.5 | 342.5 | 555.4 | 0.0 |
| 50% | 633.2 | 445.9 | 620.8 | 27.0 |
| 40% | 829.0 | 584.9 | 620.8 | 127.5 |
| 30% | 1,128 | 797.8 | 652.6 | 274.9 |
| 25% | 1,356 | 980.2 | 930.2 | 336.5 |
| 20% | 1,688 | 1,251 | 954.0 | 394.0 |
| 15% | 2,203 | 1,674 | 954.0 | 459.2 |
| 10% | 3,043 | 2,486 | 995.7 | 556.7 |
| 5% | 5,021 | 4,258 | 1,158 | 724.9 |
| 2% | 9,326 | 8,161 | 1,158 | 879.4 |
| 1% | 14,588 | 12,635 | 3,114 | 954.7 |
| 0.50% | 20,076 | 18,196 | 4,602 | 1,012 |
| Maximum | 102,858 | 101,526 | 15,868 | 1,130 |

# CHAPTER VIII

# FURTHER STATISTICAL ANALYSES OF STREAM FLOWS

Sequences of daily observed flows at USGS gauging stations and naturalized regulated, and unappropriated flows from the daily WAMs for the Sabine, Neches, and Guadalupe and San Antonio (GSA) River Basins are investigated in Chapters 7, 8, and 9 from the perspective of the environmental flow standards recently established pursuant to the Senate Bill (SB3) process. The following types of comparative analyses are performed for daily flows at gauge sites in the case study river basins for which SB3 environmental flow standards have been adopted:

1. analyses of statistical metrics of observed gauged flows during historical periods prior to significant water resources development versus during more recent periods reflecting development (Chapter 8)
2. analyses of statistical metrics for naturalized versus regulated flows from the WRAP/WAM simulations (Chapters 7 and 8)
3. analyses of unappropriated flows from the WRAM/WAM simulations with versus without the environmental flow standards (Chapter 9)

Long-term changes in river flow characteristics are important in considering environmental flows. The first two sets of analyses listed above deal with quantifying changes in flow characteristics. Two alternative approaches are adopted in Chapter 8 for quantifying long-term changes in river flow characteristics: (a) the Dundee Hydrological Regime Alteration Method (DHRAM) and (b) comparison of WAM naturalized and regulated flows.

The third set of analyses explores the effects of the environmental flow standards on flows available for water right permit applications. The SB3 process specifies that environmental flow standards be assigned priorities that are junior to all existing water right permits. The WAM simulation analyses presented in Chapter 9 compare unappropriated flows and water supply reliabilities with the SB3 environmental flow standards assigned priorities alternatively junior versus senior to all existing water rights.

## 8.1 Hydrological Regime Alteration on River Flow

The hydrological differences of daily river flow sequences, divided into impacted and un-impacted periods, are quantified using the DHRAM applied to observed daily flows at selected USGS gauging stations and WAM naturalized and regulated flows at these sites. As noted in Chapter 1, The Dundee Hydrological Regime Alteration Method (DHRAM) was developed by Black *et al.* (2005) based on the Indicator of Hydrologic Alteration (IHA) methodology developed by Richter *et al.* (1996).

The selected USGS gauging stations have SB3 environmental flow standards and daily recorded data for a long period-of-record. These USGS recorded flows are divided into the two periods before and after a major dam construction and accompanying reservoir storage. Dam construction is considered most significant point-specific human influence for the DHRAM analysis. In the simulations of daily WRAP models, naturalized flows are literally un-impacted flows, and regulated flows are theoretically impacted flows. The DHRAM analyses can be performed at all control points under these assumptions. However, the analyses based on both the flows from the simulation results are only performed at the same control points where the analyses are available based on the USGS recorded flows for the comparison of both results of the DHRAM analyses.

### 8.1.1 Assessment of USGS Recorded Flow before and after Human Influences

*Sabine River Basin*

There are five control points that have environmental flow standards. Four of these control points have daily recorded flows for relatively long term period. Control point 29500 (USGS gauge number 08029500) does not and is therefore excluded for the DHRAM analysis.

USGS gauging station 08019500(WAM control point BSBS), located on the Big Sandy Creek near Big Sandy, has daily recorded flow data for the period 1939 to present. Winnsboro Lake, located upstream of the gauging station, was initially impounded in 1962. The period-of-record is divided into two periods based on 1962. The un-impacted period is from 1940 to 1961, and impacted period is from 1962 to 2013. Table 8.1 presents the result of the analysis. Monthly average flows for each month, minimum and maximum daily flows, and flow timings of both the periods are almost similar. The analysis yields a total of 2 impact points and a corresponding DHRAM class of 2.

The USGS gauging station 08020000 (control point SRGW), located on the Sabine River near Gladewater, has daily recorded flow data for the period 1932 to present. Ten dams are located upstream of the gauging station, but two large dams, Lake Tawakoni and Lake Fork, most significantly influence the flow regime at the gauging station. Lake Tawakoni and Lake Fork were initially impounded in 1960 and 1979, respectively. The period-of-record is divided into two periods on the basis of 1960. Un-impacted period is from 1940 to 1959, and impacted period is from 1960 to 2013. Table 8.2 presents the result of the analysis. Monthly average flows for each month decrease during the impacted period. The alterations of minimum and maximum daily flows are ignorable, but flow timings of both the periods are totally different. The analysis yields a total of 5 impact points and a corresponding DHRAM class of 3.

USGS gauging station 08022040 (SRBE), located on the Sabine River near Beckville, and downstream of the control point SRGW, has the daily recorded flow data for the period 1938 to present. The period-of-record is also divided into two periods on the basis of 1960 like the control point SRGW. Table 8.3 shows the result of the analysis. Monthly average for each month and minimum and maximum daily flows for certain periods from 1 day to 90days relatively decrease during the impacted period than the un-impacted period. The average date of daily maximum for the impacted period is put forward about 80 days than the un-impacted period. The analysis yields a total of 3 impact points and a corresponding DHRAM class of 2.

USGS gauging station 08030500 (control point SRRL), located on the Sabine River near Ruliff and downstream of Toledo Bend Lake, has daily recorded flow data for the period 1924 to present. The lake has been operated since 1966. Thus, the period-of-record is also divided into two periods on the basis of 1966 like the control point SRGW. Table 8.4 provides the result of the analysis. Monthly averages for each month and minimum and maximum daily flows for certain periods from 1 day to 90days relatively decrease for the impacted period than the un-impacted period. The average date of daily maximum for the impacted period is put forward about 70 days than the un-impacted period. The analysis yields a total of 6 impact points and a corresponding HDRAM class of 3.

## Table 8.1 DHRAM Results at USGS 08029500 (Control Point BSBS)

| Control Point: | BSBS(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1961 | | 1962-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 273.4 | 0.7568 | 219.0 | 0.844 | | 19.9% | 11.5% |
| February | 297.6 | 0.6789 | 281.7 | 0.726 | | 5.3% | 6.9% |
| March | 330.2 | 1.037 | 333.9 | 0.795 | | 1.1% | 23.3% |
| April | 367.7 | 0.8362 | 261.8 | 0.841 | | 28.8% | 0.6% |
| May | 371.7 | 0.8503 | 247.9 | 0.960 | | 33.3% | 12.9% |
| June | 211.6 | 1.038 | 139.9 | 0.970 | | 33.9% | 6.5% |
| July | 79.4 | 0.8254 | 85.1 | 1.413 | | 7.2% | 71.2% |
| August | 40.8 | 0.6684 | 31.3 | 1.022 | | 23.3% | 52.9% |
| September | 45.9 | 0.6061 | 52.6 | 1.504 | | 14.7% | 148.1% |
| October | 80.1 | 1.369 | 76.8 | 2.062 | | 4.2% | 50.6% |
| November | 133.9 | 1.238 | 130.3 | 1.236 | | 2.7% | 0.2% |
| December | 220.9 | 0.7337 | 226.3 | 0.997 | | 2.4% | 35.9% |
| | | | | | Average | 14.7% | 35.1% |
| | | | | | Score | 0 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 18.16 | 0.4232 | 11.98 | 0.5596 | | 34.0% | 32.2% |
| 3-day minimum | 18.45 | 0.4329 | 12.33 | 0.5499 | | 33.2% | 27.0% |
| 7-day minimum | 19.45 | 0.4391 | 12.99 | 0.5448 | | 33.2% | 24.1% |
| 30-day minimum | 23.85 | 0.4624 | 16.83 | 0.571 | | 29.4% | 23.5% |
| 90-day minimum | 42.52 | 0.6105 | 30.87 | 0.8227 | | 27.4% | 34.8% |
| 1-day maximum | 3981 | 1.01 | 2449 | 0.7052 | | 38.5% | 30.2% |
| 3-day maximum | 3021 | 0.8916 | 1957 | 0.6424 | | 35.2% | 27.9% |
| 7-day maximum | 1936 | 0.8138 | 1348 | 0.5455 | | 30.4% | 33.0% |
| 30-day maximum | 768.8 | 0.6372 | 635.4 | 0.5349 | | 17.4% | 16.1% |
| 90-day maximum | 436.5 | 0.5317 | 383.1 | 0.5146 | | 12.2% | 3.2% |
| | | | | | Average | 29.1% | 25.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 231.7 | 0.06215 | 240.3 | 0.08241 | | 3.7% | 32.6% |
| Date of maximum | 121.5 | 0.2271 | 140.7 | 0.2987 | | 15.8% | 31.5% |
| | | | | | Average | 9.8% | 32.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.636 | 0.5093 | 5.519 | 0.3737 | | 19.0% | 26.6% |
| Low pulse duration | 23.2 | 0.9133 | 21.49 | 0.5079 | | 7.4% | 44.4% |
| High pulse count | 4.318 | 0.7874 | 4.019 | 0.7577 | | 6.9% | 3.8% |
| High pulse duration | 4.652 | 0.4071 | 4.73 | 0.6026 | | 1.7% | 48.0% |
| | | | | | Average | 8.8% | 30.7% |
| | | | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 88.6 | 0.7507 | 64.83 | 0.6987 | | 26.8% | 6.9% |
| Fall rate | -48.05 | -0.7083 | -35.21 | -0.6589 | | 26.7% | 7.0% |
| Number of reversals | 76.5 | 0.09232 | 86.23 | 0.117 | | 12.7% | 26.7% |
| | | | | | Average | 22.1% | 13.5% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 3 |
| Classification | 2 |
| note: | Low risk of impact |

Table 8.2 DHRAM Results at USGS 08020000 (Control Point SRGW)

| Control Point: | SRBE(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1959 | | 1960-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 2920.0 | 0.8549 | 3385.0 | 0.972 | | 15.9% | 13.7% |
| February | 3599.0 | 0.9182 | 3919.0 | 0.752 | | 8.9% | 18.1% |
| March | 3836.0 | 0.9104 | 4503.0 | 0.858 | | 17.4% | 5.8% |
| April | 4843.0 | 1.264 | 3646.0 | 0.860 | | 24.7% | 31.9% |
| May | 7125.0 | 0.9237 | 3913.0 | 1.042 | | 45.1% | 12.8% |
| June | 4323.0 | 1.093 | 2392.0 | 1.056 | | 44.7% | 3.4% |
| July | 1078.0 | 1.359 | 1090.0 | 1.710 | | 1.1% | 25.8% |
| August | 466.3 | 1.223 | 337.2 | 1.336 | | 27.7% | 9.2% |
| September | 435.6 | 0.82 | 445.7 | 1.333 | | 2.3% | 62.6% |
| October | 785.4 | 1.33 | 797.2 | 2.042 | | 1.5% | 53.5% |
| November | 1941.0 | 1.553 | 1617.0 | 1.310 | | 16.7% | 15.6% |
| December | 2161.0 | 1.015 | 2990.0 | 1.056 | | 38.4% | 4.0% |
| | | | | | Average | 20.4% | 21.4% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 79.89 | 0.6591 | 62.79 | 0.6443 | | 21.4% | 2.2% |
| 3-day minimum | 83.46 | 0.6797 | 66.12 | 0.6274 | | 20.8% | 7.7% |
| 7-day minimum | 90.75 | 0.7075 | 71.89 | 0.6155 | | 20.8% | 13.0% |
| 30-day minimum | 145.9 | 0.8675 | 107.2 | 0.6236 | | 26.5% | 28.1% |
| 90-day minimum | 378.8 | 0.9232 | 274.1 | 0.9777 | | 27.6% | 5.9% |
| 1-day maximum | 30450 | 0.9384 | 15210 | 0.6185 | | 50.0% | 34.1% |
| 3-day maximum | 28690 | 0.9349 | 14400 | 0.5959 | | 49.8% | 36.3% |
| 7-day maximum | 23640 | 0.8706 | 12900 | 0.5741 | | 45.4% | 34.1% |
| 30-day maximum | 11980 | 0.6614 | 8777 | 0.5506 | | 26.7% | 16.8% |
| 90-day maximum | 6539 | 0.6169 | 5684 | 0.5471 | | 13.1% | 11.3% |
| | | | | | Average | 30.2% | 18.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 257.8 | 0.0719 | 250.2 | 0.09071 | | 2.9% | 26.2% |
| Date of maximum | 142.7 | 0.212 | 62.93 | 0.1872 | | 55.9% | 11.7% |
| | | | | | Average | 29.4% | 18.9% |
| | | | | | Score | 2 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.55 | 0.4702 | 5.074 | 0.5062 | | 42.9% | 7.7% |
| Low pulse duration | 28.76 | 0.7992 | 25.34 | 0.7494 | | 11.9% | 6.2% |
| High pulse count | 2.15 | 0.8024 | 2.389 | 0.8583 | | 11.1% | 7.0% |
| High pulse duration | 12.29 | 0.5222 | 11.92 | 0.6441 | | 3.0% | 23.3% |
| | | | | | Average | 17.2% | 11.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 469.2 | 0.6892 | 367.2 | 0.5129 | | 21.7% | 25.6% |
| Fall rate | -327.4 | -0.6447 | -213.6 | -0.4756 | | 34.8% | 26.2% |
| Number of reversals | 61.75 | 0.1373 | 85.41 | 0.2142 | | 38.3% | 56.0% |
| | | | | | Average | 31.6% | 35.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 3 |
| Classification | 2 |
| note: | Low risk of impact |

Table 8.3 DHRAM results at USGS 08022040 (Control Point SRBE)

| Control Point: | SRGW(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1959 | | 1960-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 2126.0 | 0.8537 | 2170.0 | 1.040 | | 2.1% | 21.8% |
| February | 2888.0 | 1.092 | 2617.0 | 0.889 | | 9.4% | 18.6% |
| March | 2872.0 | 0.9689 | 3327.0 | 0.918 | | 15.8% | 5.3% |
| April | 4437.0 | 1.245 | 2505.0 | 0.932 | | 43.5% | 25.1% |
| May | 5495.0 | 0.9335 | 3205.0 | 1.192 | | 41.7% | 27.7% |
| June | 3734.0 | 1.181 | 1613.0 | 1.075 | | 56.8% | 9.0% |
| July | 707.0 | 1.316 | 757.3 | 1.924 | | 7.1% | 46.2% |
| August | 301.5 | 1.298 | 213.6 | 1.304 | | 29.2% | 0.5% |
| September | 317.8 | 0.8499 | 304.6 | 1.430 | | 4.2% | 68.3% |
| October | 683.5 | 1.39 | 630.5 | 2.408 | | 7.8% | 73.2% |
| November | 1555.0 | 1.689 | 1206.0 | 1.455 | | 22.4% | 13.9% |
| December | 1851.0 | 1.118 | 2274.0 | 1.225 | | 22.9% | 9.6% |
| | | | | | Average | 21.9% | 26.6% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 48.1 | 0.6842 | 47.99 | 0.5402 | | 0.2% | 21.0% |
| 3-day minimum | 50.5 | 0.6921 | 49.63 | 0.5402 | | 1.7% | 21.9% |
| 7-day minimum | 55.13 | 0.6873 | 53.19 | 0.5228 | | 3.5% | 23.9% |
| 30-day minimum | 95.09 | 0.9114 | 75.61 | 0.561 | | 20.5% | 38.4% |
| 90-day minimum | 264.8 | 0.9516 | 176.7 | 0.9283 | | 33.3% | 2.4% |
| 1-day maximum | 32490 | 0.931 | 15020 | 0.741 | | 53.8% | 20.4% |
| 3-day maximum | 30010 | 0.8761 | 14460 | 0.7311 | | 51.8% | 16.6% |
| 7-day maximum | 24250 | 0.8049 | 12730 | 0.6986 | | 47.5% | 13.2% |
| 30-day maximum | 10590 | 0.6477 | 7347 | 0.612 | | 30.6% | 5.5% |
| 90-day maximum | 5418 | 0.6327 | 4296 | 0.5885 | | 20.7% | 7.0% |
| | | | | | Average | 26.4% | 17.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 248.6 | 0.06424 | 248.9 | 0.09245 | | 0.1% | 43.9% |
| Date of maximum | 146.8 | 0.2637 | 62.8 | 0.1787 | | 57.2% | 32.2% |
| | | | | | Average | 28.7% | 38.1% |
| | | | | | Score | 2 | 1 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.05 | 0.4199 | 4.87 | 0.5903 | | 20.2% | 40.6% |
| Low pulse duration | 23.35 | 0.7018 | 24.93 | 0.5609 | | 6.8% | 20.1% |
| High pulse count | 2.35 | 0.7843 | 1.37 | 0.9749 | | 41.7% | 24.3% |
| High pulse duration | 9.719 | 0.3032 | 11.54 | 0.4799 | | 18.7% | 58.3% |
| | | | | | Average | 21.9% | 35.8% |
| | | | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 478 | 0.715 | 268.5 | 0.5813 | | 43.8% | 18.7% |
| Fall rate | -366.1 | -0.717 | -169.4 | -0.5416 | | 53.7% | 24.5% |
| Number of reversals | 60.55 | 0.1603 | 67.85 | 0.137 | | 12.1% | 14.5% |
| | | | | | Average | 36.5% | 19.2% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 5 |
| Classification | 3 |
| note: | Moderate risk of impact |

## Table 8.4 DHRAM results at USGS 08030500 (Control Point SRRL)

| Control Point: | SRRL(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1965 | | 1966-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 13800.0 | 0.8227 | 10910.0 | 0.745 | | 20.9% | 9.4% |
| February | 14740.0 | 0.5986 | 12470.0 | 0.629 | | 15.4% | 5.0% |
| March | 13940.0 | 0.5539 | 13010.0 | 0.724 | | 6.7% | 30.8% |
| April | 13260.0 | 0.7929 | 10820.0 | 0.727 | | 18.4% | 8.3% |
| May | 15920.0 | 0.9414 | 9310.0 | 0.888 | | 41.5% | 5.6% |
| June | 10570.0 | 1.013 | 7200.0 | 0.766 | | 31.9% | 24.4% |
| July | 5182.0 | 0.898 | 5879.0 | 1.033 | | 13.5% | 15.0% |
| August | 2878.0 | 1.062 | 4330.0 | 0.510 | | 50.5% | 52.0% |
| September | 2709.0 | 1.079 | 4073.0 | 0.714 | | 50.4% | 33.9% |
| October | 2458.0 | 1.149 | 2985.0 | 1.027 | | 21.4% | 10.6% |
| November | 4749.0 | 1.212 | 4334.0 | 1.118 | | 8.7% | 7.8% |
| December | 9158.0 | 1.106 | 8007.0 | 0.816 | | 12.6% | 26.2% |
| | | | | | Average | 24.3% | 19.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 857.4 | 0.521 | 870.8 | 0.3784 | | 1.6% | 27.4% |
| 3-day minimum | 870.3 | 0.5278 | 936.5 | 0.4217 | | 7.6% | 20.1% |
| 7-day minimum | 897.7 | 0.5322 | 1031 | 0.4773 | | 14.8% | 10.3% |
| 30-day minimum | 1116 | 0.57 | 1392 | 0.6109 | | 24.7% | 7.2% |
| 90-day minimum | 1896 | 0.6886 | 2436 | 0.6029 | | 28.5% | 12.4% |
| 1-day maximum | 44830 | 0.5375 | 40620 | 0.5783 | | 9.4% | 7.6% |
| 3-day maximum | 43520 | 0.548 | 38650 | 0.5822 | | 11.2% | 6.2% |
| 7-day maximum | 40000 | 0.568 | 33670 | 0.5759 | | 15.8% | 1.4% |
| 30-day maximum | 28320 | 0.5734 | 21950 | 0.497 | | 22.5% | 13.3% |
| 90-day maximum | 18900 | 0.5056 | 15060 | 0.4903 | | 20.3% | 3.0% |
| | | | | | Average | 15.6% | 10.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 275.5 | 0.07237 | 288.2 | 0.1136 | | 4.6% | 57.0% |
| Date of maximum | 128.4 | 0.2649 | 52.29 | 0.2024 | | 59.3% | 23.6% |
| | | | | | Average | 31.9% | 40.3% |
| | | | | | Score | 2 | 1 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.4 | 0.5023 | 8.714 | 0.65 | | 156.3% | 29.4% |
| Low pulse duration | 29.51 | 0.6863 | 13.51 | 0.9187 | | 54.2% | 33.9% |
| High pulse count | 2.96 | 0.6577 | 2.939 | 0.8547 | | 0.7% | 30.0% |
| High pulse duration | 14.23 | 0.758 | 8.544 | 0.5868 | | 40.0% | 22.6% |
| | | | | | Average | 62.8% | 29.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 1068 | 0.4124 | 869.6 | 0.3499 | | 18.6% | 15.2% |
| Fall rate | -684.9 | -0.4158 | -768.9 | -0.3791 | | 12.3% | 8.8% |
| Number of reversals | 50.76 | 0.1176 | 93.8 | 0.2811 | | 84.8% | 139.0% |
| | | | | | Average | 38.5% | 54.3% |
| | | | | | Score | 0 | 1 |

| | |
|---|---|
| Total Point | 6 |
| Classification | 3 |
| note: | Moderate risk of impact |

*Neches River Basin*

The Neches River Basin has five control points that have environmental flow standards. All the five control points have daily recorded flow for long term periods. However, control points ANAL (USGS gauge number 08036500) has a significant gap of missing data. This control point is, therefore, excluded for the DHRAM analysis.

The USGS gauging station (08032000, NENE) located on the Neches River at Neches, and downstream of Palestine Lake, has daily recorded flow data for the period 1939 to present. The Palestine Lake has been operated since 1962. The period-of-record is divided into two periods on the basis of 1962. Table 8.5 presents the result of the analysis. Monthly average flows for each month for the impacted period are smaller than the un-impacted period. Minimum and maximum daily flows for certain periods from 1 day to 90days increase and decrease, respectively for the impacted period than the un-impacted period. The average date of daily maximum flow for the impacted period is put forward about 60 days than the un-impacted period. The analysis yields a total of 8 impact points and a corresponding DHRAM class of 3.

The USGS gauging station (08033500, NERO) located on the Neches River near Rockland, and downstream of the control point NENE, has daily recorded flow data for the period 1903 to present. The period-of-record is divided into two periods on the basis of 1962 like the control point NENE. Table 8.6 provides the result of the analysis. Monthly average flows for each month for the impacted period are also smaller than the un-impacted period, but the differences between both the periods are insignificant. Minimum and maximum daily flows for certain periods from 1 day to 90 days slightly increase and decrease, respectively, for the impacted period than the impacted period. However, flow timings for both periods are almost similar. The analysis yields a total of 0 impact points and a corresponding DHRAM class of 1.

The USGS gauging station (08041000, NEEV) located on the Neches River at Evadale, and downstream of Sam Rayburn and Town Bluff dams, has daily recorded flow data for the period 1904 to present. The Sam Rayburn was initially impounded in 1965. Thus, the period-of-record is divided into two periods on the basis of 1965. Table 8.7

provides the result of the analysis. Monthly average flows from July to September for the impacted period tremendously increase than the un-impacted period. Minimum daily flows for certain periods for the impacted period are significantly larger than the un-impacted period while maximum flows for certain period slightly decrease than the un-impacted period. The average date of daily maximum flow for the impacted period is put forward about 60 days than the un-impacted period. The analysis yields a total of 10 impact points and a corresponding DHRAM class of 3.

The USGS gauging station (08041500, VIKO) located on the Village Creek near Kountze has the daily recorded flow data for the period 1924 to present. There are no serious human influences upstream of the station. The period-of-record is divided into two periods on the basis of 1977 that is the middle year for the period-of-record. Table 8.8 provides the result of the analysis. Monthly average flows for the impacted period increase than the un-impacted period. The average date of daily maximum flow for the impacted period is put off about 140 days than the un-impacted period. The analysis yields a total of 4 impact points and a corresponding DHRAM class of 2.

*GSA River Basins*

The GSA River Basins have fifteen control points that have environmental flow standards. Of the 15 control points, only six control points, CP01, CP02, CP08, CP10, CP15, and CP35 do not have periods of missing data during the periods-of-record. These recorded data are therefore analyzed by the DHRAM method after dividing into un-impacted and impacted periods at these control points. The control points that have daily recorded flow without missing period along the San Antonio River are excluded in the DHRAM analysis because the flow regime of the San Antonio River has been totally influenced by the operation of Medina Lake since 1913.

The USGS gauging station (08167000, CP01) located on the Guadalupe River at Comfort, and upstream of Canyon Lake, has daily recorded flow data for the period 1939 to present. It is difficult to find the turning point the moment the flow regime obviously had been changed for the period-of-record at the gauging station. Thus, the period-of-record is divided into two periods on the basis of 1976 that is the middle year for the period-of-record. Table 8.9 presents the results of the analysis. The monthly average flows and minimum and maximum flows for certain days for the impacted period significantly increase than the un-impacted period, but the flow timings are almost identical. The analysis yields a total of 9 impact points and a corresponding DHRAM class of 3.

The USGS gauging station (08167500, CP02) located on the Guadalupe River near Spring Branch, and upstream of Canyon Lake, has daily recorded flow data for the period 1934 to present. This gauge also doesn't have the obvious turning point for the period-of-record like the USGS gauge 08167000. The period-of-record is, therefore, divided into two periods on the basis of 1974 that is the middle year for the period-of-record. Table 8.10 presents the result of the analysis. The analysis results are almost similar to the control point CP01. The analysis yields a total of 7 impact points and a corresponding DHRAM class of 3.

The USGS gauging station (08171000, CP08) located on the Blanco River at Wimberley, has daily recorded flow data for the period 1934 to present. There are no obvious human influences on the flow regime at this gauge for the period-of-record. The period-of-record is, therefore, divided into two periods on the basis of 1974 that is the middle year for the period-of-record. Table 8.11 presents the result of the analysis. The analysis results are almost the same as the CP01 and CP02. The analysis yields a total of 6 impact points and a corresponding DHRAM class of 3.

The USGS gauging station (08172000, CP10) located on the San Marcos River at Luling has the daily recorded flow data for the period 1939 to present. There are also no obvious human influences on the flow regime at this gauge for the period-of-record. The period-of-record is, therefore, divided into two periods on the basis of 1976 that is the middle year for the period-of-record. Table 8.12 presents the result of the analysis. The analysis results are almost the same as the CP01, CP02, and CP08 even though the differences between both the periods are smaller than others. The analysis yields a total of 2 impact points and a corresponding DHRAM class of 2.

The USGS gauging station (08176500, CP15) located on the Guadalupe River at Vitoria, and downstream far from Canyon Lake, has daily recorded flow data for the period 1934 to present. Canyon Lake has been operated since 1964. The period-of-record is, therefore, divided into two periods based on 1964. Table 8.13 presents the result of the analysis. The analysis results are almost the same as the CP10. The analysis yields a total of 1 impact points and a corresponding DHRAM class of 2.

The USGS gauging station (08186000, CP35) located on the Cibolo Creek near Falls City has daily recorded flow data for the period 1930 to present. There are also no clear human influences on the flow regime at this gauge for the period-of-record. The period-of-record is, therefore, divided into two periods on the basis of 1973 that is the middle year for the period-of-record. Table 8.14 presents the result of the analysis. The analysis results are almost the same as the above control points. The analysis yields a total of seven impact points and a corresponding DHRAM class of 3.

## Table 8.5 DHRAM results at USGS 08032000 (Control Point NENE)

Control Point: NENE(USGS) Period: 1940-2013

| IHA statistics group | 1940-1961 | | 1962-2013 | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1153.0 | 0.8116 | 845.2 | 1.094 | | 26.7% | 34.8% |
| February | 1230.0 | 0.7364 | 1041.0 | 0.757 | | 15.4% | 2.7% |
| March | 1327.0 | 0.7282 | 1246.0 | 0.753 | | 6.1% | 3.4% |
| April | 1498.0 | 1.058 | 1081.0 | 0.895 | | 27.8% | 15.4% |
| May | 1675.0 | 0.8675 | 1088.0 | 1.046 | | 35.0% | 20.6% |
| June | 787.4 | 1.075 | 709.7 | 1.082 | | 9.9% | 0.7% |
| July | 244.9 | 1.161 | 325.0 | 2.564 | | 32.7% | 120.8% |
| August | 74.9 | 1.248 | 128.2 | 0.970 | | 71.3% | 22.3% |
| September | 121.5 | 1.639 | 187.3 | 1.382 | | 54.2% | 15.7% |
| October | 228.9 | 1.169 | 251.6 | 1.861 | | 9.9% | 59.2% |
| November | 576.8 | 1.535 | 415.0 | 1.285 | | 28.1% | 16.3% |
| December | 814.0 | 1.017 | 732.2 | 1.096 | | 10.0% | 7.8% |
| | | | | | Average | 27.3% | 26.6% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 23.27 | 0.7129 | 64.9 | 0.5399 | | 178.9% | 24.3% |
| 3-day minimum | 24.44 | 0.721 | 66.63 | 0.5295 | | 172.6% | 26.6% |
| 7-day minimum | 26.48 | 0.7308 | 68.73 | 0.5221 | | 159.6% | 28.6% |
| 30-day minimum | 38.75 | 0.7246 | 81.34 | 0.5339 | | 109.9% | 26.3% |
| 90-day minimum | 108.1 | 1.198 | 124.3 | 0.9416 | | 15.0% | 21.4% |
| 1-day maximum | 11010 | 0.8298 | 6370 | 0.8797 | | 42.1% | 6.0% |
| 3-day maximum | 10090 | 0.8044 | 5956 | 0.8565 | | 41.0% | 6.5% |
| 7-day maximum | 7869 | 0.7363 | 4925 | 0.812 | | 37.4% | 10.3% |
| 30-day maximum | 3331 | 0.5409 | 2563 | 0.6157 | | 23.1% | 13.8% |
| 90-day maximum | 1911 | 0.4962 | 1561 | 0.5725 | | 18.3% | 15.4% |
| | | | | | Average | 79.8% | 17.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 247 | 0.05489 | 237.7 | 0.1327 | | 3.8% | 141.8% |
| Date of maximum | 130.5 | 0.2121 | 74.38 | 0.1885 | | 43.0% | 11.1% |
| | | | | | Average | 23.4% | 76.4% |
| | | | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.227 | 0.4775 | 3.981 | 0.8346 | | 23.4% | 74.8% |
| Low pulse duration | 40.44 | 1.074 | 23.36 | 1.186 | | 42.2% | 10.4% |
| High pulse count | 3.227 | 0.7215 | 1.962 | 0.8971 | | 39.2% | 24.3% |
| High pulse duration | 7.816 | 0.3388 | 8.891 | 0.4013 | | 13.8% | 18.4% |
| | | | | | Average | 29.6% | 32.0% |
| | | | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 205.6 | 0.6876 | 137.2 | 0.696 | | 33.3% | 1.2% |
| Fall rate | -112.7 | -0.5826 | -67.11 | -0.6445 | | 40.5% | 10.6% |
| Number of reversals | 56.27 | 0.1625 | 78.92 | 0.1661 | | 40.3% | 2.2% |
| | | | | | Average | 38.0% | 4.7% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 8 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 8.6 DHRAM results at USGS 08033500 (Control Point NERO)

| Control Point: | NERO(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1961 | | 1962-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 4053.0 | 0.9705 | 3564.0 | 0.996 | | 12.1% | 2.7% |
| February | 4270.0 | 0.7708 | 4077.0 | 0.744 | | 4.5% | 3.5% |
| March | 4020.0 | 0.6792 | 4198.0 | 0.821 | | 4.4% | 20.9% |
| April | 3967.0 | 0.9121 | 3404.0 | 0.800 | | 14.2% | 12.3% |
| May | 5481.0 | 1.073 | 3225.0 | 0.937 | | 41.2% | 12.6% |
| June | 2674.0 | 0.8613 | 2368.0 | 1.166 | | 11.4% | 35.4% |
| July | 904.6 | 0.9399 | 1230.0 | 1.801 | | 36.0% | 91.6% |
| August | 337.9 | 1.048 | 406.6 | 1.514 | | 20.3% | 44.5% |
| September | 403.0 | 1.237 | 455.4 | 1.239 | | 13.0% | 0.2% |
| October | 627.1 | 1.291 | 859.6 | 1.950 | | 37.1% | 51.0% |
| November | 1844.0 | 1.574 | 1563.0 | 1.368 | | 15.2% | 13.1% |
| December | 2737.0 | 1.26 | 2528.0 | 0.959 | | 7.6% | 23.9% |
| | | | | | Average | 18.1% | 26.0% |
| | | | | | Score | **0** | **0** |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 91.09 | 0.7557 | 110.2 | 0.607 | | 21.0% | 19.7% |
| 3-day minimum | 93.52 | 0.7605 | 112.6 | 0.6127 | | 20.4% | 19.4% |
| 7-day minimum | 99.07 | 0.7664 | 118.1 | 0.6139 | | 19.2% | 19.9% |
| 30-day minimum | 131.7 | 0.7609 | 161.8 | 0.7516 | | 22.9% | 1.2% |
| 90-day minimum | 315.9 | 0.9481 | 303.8 | 0.9812 | | 3.8% | 3.5% |
| 1-day maximum | 18110 | 0.6856 | 16290 | 0.6045 | | 10.0% | 11.8% |
| 3-day maximum | 17590 | 0.6857 | 15680 | 0.6034 | | 10.9% | 12.0% |
| 7-day maximum | 15910 | 0.6747 | 13930 | 0.5877 | | 12.4% | 12.9% |
| 30-day maximum | 9558 | 0.6412 | 8216 | 0.5332 | | 14.0% | 16.8% |
| 90-day maximum | 5907 | 0.5475 | 5210 | 0.5589 | | 11.8% | 2.1% |
| | | | | | Average | 14.6% | 11.9% |
| | | | | | Score | **0** | **0** |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 258 | 0.1711 | 257.8 | 0.07513 | | 0.1% | 56.1% |
| Date of maximum | 131 | 0.2506 | 139.8 | 0.2694 | | 6.7% | 7.5% |
| | | | | | Average | 3.4% | 31.8% |
| | | | | | Score | **0** | **0** |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.045 | 0.4586 | 3.769 | 0.5137 | | 23.8% | 12.0% |
| Low pulse duration | 39.26 | 1.011 | 30.61 | 1.004 | | 22.0% | 0.7% |
| High pulse count | 2.773 | 0.7207 | 2.788 | 0.7758 | | 0.5% | 7.6% |
| High pulse duration | 14.91 | 0.6251 | 11.12 | 0.5513 | | 25.4% | 11.8% |
| | | | | | Average | 17.9% | 8.0% |
| | | | | | Score | **0** | **0** |
| Parameter Group #5 | | | | | | | |
| Rise rate | 383.5 | 0.5392 | 407.5 | 0.5681 | | 6.3% | 5.4% |
| Fall rate | -209.7 | -0.5431 | -204.5 | -0.5587 | | 2.5% | 2.9% |
| Number of reversals | 59.91 | 0.1505 | 68.71 | 0.1538 | | 14.7% | 2.2% |
| | | | | | Average | 7.8% | 3.5% |
| | | | | | Score | **0** | **0** |

| Total Point | | 0 |
|---|---|---|
| Classification | | 1 |
| note: | Un-impacted condition | |

Table 8.7 DHRAM results at USGS 08041000 (Control Point NEEV)

| Control Point: | NEEV(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1964 | | 1965-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 9980.0 | 0.9255 | 7290.0 | 0.843 | | 27.0% | 8.9% |
| February | 10560.0 | 0.7117 | 8744.0 | 0.725 | | 17.2% | 1.9% |
| March | 9862.0 | 0.6156 | 9984.0 | 0.760 | | 1.2% | 23.4% |
| April | 9167.0 | 0.7086 | 8951.0 | 0.709 | | 2.4% | 0.0% |
| May | 12050.0 | 1.039 | 7722.0 | 0.766 | | 35.9% | 26.3% |
| June | 6486.0 | 0.9567 | 6664.0 | 0.820 | | 2.7% | 14.3% |
| July | 2520.0 | 0.7021 | 5094.0 | 0.898 | | 102.1% | 27.9% |
| August | 1343.0 | 0.7074 | 3346.0 | 0.661 | | 149.1% | 6.6% |
| September | 1298.0 | 0.962 | 2951.0 | 0.527 | | 127.3% | 45.2% |
| October | 1707.0 | 1.305 | 3055.0 | 0.861 | | 79.0% | 34.0% |
| November | 3615.0 | 1.569 | 3720.0 | 0.864 | | 2.9% | 44.9% |
| December | 6873.0 | 1.396 | 5233.0 | 0.831 | | 23.9% | 40.5% |
| | | | | | Average | 47.6% | 22.8% |
| | | | | | Score | **2** | **0** |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 374.8 | 0.7416 | 1336 | 0.6506 | | 256.5% | 12.3% |
| 3-day minimum | 387.1 | 0.7487 | 1380 | 0.6326 | | 256.5% | 15.5% |
| 7-day minimum | 408.8 | 0.7276 | 1485 | 0.601 | | 263.3% | 17.4% |
| 30-day minimum | 534.4 | 0.6818 | 1828 | 0.534 | | 242.1% | 21.7% |
| 90-day minimum | 1010 | 0.7764 | 2334 | 0.5064 | | 131.1% | 34.8% |
| 1-day maximum | 34700 | 0.6253 | 21520 | 0.4239 | | 38.0% | 32.2% |
| 3-day maximum | 34150 | 0.6241 | 20890 | 0.4319 | | 38.8% | 30.8% |
| 7-day maximum | 32230 | 0.6263 | 19230 | 0.4502 | | 40.3% | 28.1% |
| 30-day maximum | 21420 | 0.6448 | 14840 | 0.4931 | | 30.7% | 23.5% |
| 90-day maximum | 13680 | 0.5608 | 11440 | 0.5578 | | 16.4% | 0.5% |
| | | | | | Average | 131.4% | 21.7% |
| | | | | | Score | **2** | **0** |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 284.9 | 0.09446 | 318.3 | 0.2093 | | 11.7% | 121.6% |
| Date of maximum | 119.5 | 0.261 | 63.45 | 0.209 | | 46.9% | 19.9% |
| | | | | | Average | 29.3% | 70.7% |
| | | | | | Score | **2** | **3** |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.6 | 0.5893 | 2 | 1.35 | | 44.4% | 129.1% |
| Low pulse duration | 29.52 | 0.8241 | 14.38 | 1.001 | | 51.3% | 21.5% |
| High pulse count | 2.4 | 0.6697 | 2.02 | 1.008 | | 15.8% | 50.5% |
| High pulse duration | 17.8 | 0.718 | 21.93 | 0.8367 | | 23.2% | 16.5% |
| | | | | | Average | 33.7% | 54.4% |
| | | | | | Score | **0** | **1** |
| Parameter Group #5 | | | | | | | |
| Rise rate | 693.5 | 0.4347 | 497.9 | 0.3784 | | 28.2% | 13.0% |
| Fall rate | -486.5 | -0.421 | -375 | -0.4057 | | 22.9% | 3.6% |
| Number of reversals | 60.24 | 0.1864 | 78.31 | 0.1568 | | 30.0% | 15.9% |
| | | | | | Average | 27.0% | 10.8% |
| | | | | | Score | **0** | **0** |

| | | |
|---|---|---|
| Total Point | | 10 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 8.8 DHRAM results at USGS 08041500 (Control Point VIKO)

| Control Point: | VIKO(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1976 | | 1977-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1386.0 | 1.016 | 1438.0 | 0.746 | | 3.8% | 26.5% |
| February | 1316.0 | 0.7582 | 1649.0 | 0.655 | | 25.3% | 13.6% |
| March | 1020.0 | 0.6697 | 1319.0 | 0.595 | | 29.3% | 11.1% |
| April | 1028.0 | 0.8626 | 1120.0 | 1.092 | | 8.9% | 26.6% |
| May | 1203.0 | 1.093 | 941.6 | 1.113 | | 21.7% | 1.8% |
| June | 786.5 | 1.559 | 806.7 | 1.176 | | 2.6% | 24.6% |
| July | 429.0 | 1.043 | 553.0 | 1.542 | | 28.9% | 47.8% |
| August | 261.5 | 1.341 | 239.7 | 0.995 | | 8.3% | 25.8% |
| September | 299.5 | 1.374 | 347.7 | 1.237 | | 16.1% | 10.0% |
| October | 356.9 | 1.993 | 673.8 | 2.335 | | 88.8% | 17.2% |
| November | 746.8 | 1.708 | 874.6 | 1.278 | | 17.1% | 25.2% |
| December | 1005.0 | 1.116 | 1191.0 | 0.827 | | 18.5% | 25.9% |
| | | | | | Average | 22.4% | 21.3% |
| | | | | | Score | **1** | **0** |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 78.05 | 0.6986 | 75.95 | 0.4939 | | 2.7% | 29.3% |
| 3-day minimum | 79.45 | 0.7047 | 77.61 | 0.4972 | | 2.3% | 29.4% |
| 7-day minimum | 82.67 | 0.728 | 81.32 | 0.5073 | | 1.6% | 30.3% |
| 30-day minimum | 109.8 | 0.973 | 105.3 | 0.5263 | | 4.1% | 45.9% |
| 90-day minimum | 189.3 | 1.052 | 188.9 | 0.8197 | | 0.2% | 22.1% |
| 1-day maximum | 13130 | 1.07 | 14660 | 0.8553 | | 11.7% | 20.1% |
| 3-day maximum | 10810 | 0.9765 | 12320 | 0.8058 | | 14.0% | 17.5% |
| 7-day maximum | 7108 | 0.8081 | 8411 | 0.7403 | | 18.3% | 8.4% |
| 30-day maximum | 3035 | 0.7291 | 3522 | 0.5403 | | 16.0% | 25.9% |
| 90-day maximum | 1714 | 0.5746 | 2017 | 0.4526 | | 17.7% | 21.2% |
| | | | | | Average | 8.9% | 25.0% |
| | | | | | Score | **0** | **0** |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 254 | 0.1031 | 254.7 | 0.09211 | | 0.3% | 10.7% |
| Date of maximum | 163.2 | 0.2766 | 301.7 | 0.311 | | 84.9% | 12.4% |
| | | | | | Average | 42.6% | 11.5% |
| | | | | | Score | **3** | **0** |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.514 | 0.6841 | 4.973 | 0.5948 | | 10.2% | 13.1% |
| Low pulse duration | 21.91 | 0.7163 | 15.68 | 0.7503 | | 28.4% | 4.7% |
| High pulse count | 4 | 0.8539 | 4.946 | 0.6688 | | 23.7% | 21.7% |
| High pulse duration | 5.547 | 0.3702 | 5.866 | 0.3352 | | 5.8% | 9.5% |
| | | | | | Average | 17.0% | 12.2% |
| | | | | | Score | **0** | **0** |
| Parameter Group #5 | | | | | | | |
| Rise rate | 303.8 | 0.7268 | 335.3 | 0.5706 | | 10.4% | 21.5% |
| Fall rate | -164.2 | -0.774 | -176.4 | -0.6086 | | 7.4% | 21.4% |
| Number of reversals | 69.78 | 0.1055 | 71.41 | 0.08268 | | 2.3% | 21.6% |
| | | | | | Average | 6.7% | 21.5% |
| | | | | | Score | **0** | **0** |

| | | |
|---|---|---|
| Total Point | | 4 |
| Classification | | 2 |
| note: | Low risk of impact | |

Table 8.9 DHRAM results at USGS 08167000 (Control Point CP01)

| Control Point: | CP01(USGS) | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1975 | | 1976-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 144.5 | 1.072 | 198.5 | 0.843 | | 37.4% | 21.3% |
| February | 184.8 | 1.073 | 238.6 | 1.173 | | 29.1% | 9.3% |
| March | 158.5 | 0.8727 | 272.9 | 0.999 | | 72.2% | 14.4% |
| April | 183.3 | 0.9184 | 303.4 | 1.170 | | 65.5% | 27.4% |
| May | 263.6 | 1.118 | 298.1 | 0.918 | | 13.1% | 17.9% |
| June | 158.8 | 0.9292 | 396.9 | 1.632 | | 149.9% | 75.6% |
| July | 86.1 | 1.001 | 395.1 | 2.488 | | 358.8% | 148.6% |
| August | 147.4 | 2.089 | 290.0 | 2.748 | | 96.7% | 31.5% |
| September | 128.4 | 1.088 | 179.2 | 0.977 | | 39.6% | 10.2% |
| October | 226.5 | 1.257 | 290.5 | 1.476 | | 28.3% | 17.4% |
| November | 134.5 | 0.9117 | 235.4 | 1.128 | | 75.0% | 23.7% |
| December | 132.6 | 0.8372 | 256.0 | 1.680 | | 93.1% | 100.7% |
| | | | | | Average | 88.2% | 41.5% |
| | | | | | Score | 3 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 28.56 | 1.08 | 54.05 | 0.8358 | | 89.3% | 22.6% |
| 3-day minimum | 29.31 | 1.064 | 55.55 | 0.8266 | | 89.5% | 22.3% |
| 7-day minimum | 30.97 | 1.049 | 58.74 | 0.8021 | | 89.7% | 23.5% |
| 30-day minimum | 36.74 | 0.9606 | 68.4 | 0.7329 | | 86.2% | 23.7% |
| 90-day minimum | 55.79 | 0.8003 | 95.83 | 0.7098 | | 71.8% | 11.3% |
| 1-day maximum | 5661 | 1.085 | 12240 | 1.288 | | 116.2% | 18.7% |
| 3-day maximum | 2905 | 0.9678 | 6727 | 1.431 | | 131.6% | 47.9% |
| 7-day maximum | 1596 | 0.8675 | 3506 | 1.414 | | 119.7% | 63.0% |
| 30-day maximum | 602.5 | 0.7139 | 1202 | 1.138 | | 99.5% | 59.4% |
| 90-day maximum | 331.2 | 0.6515 | 624.4 | 0.9187 | | 88.5% | 41.0% |
| | | | | | Average | 98.2% | 33.3% |
| | | | | | Score | 2 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 210.4 | 0.1445 | 216.3 | 0.1923 | | 2.8% | 33.1% |
| Date of maximum | 181.2 | 0.2212 | 182.1 | 0.2669 | | 0.5% | 20.7% |
| | | | | | Average | 1.7% | 26.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.306 | 0.9991 | 2.316 | 1.695 | | 46.2% | 69.7% |
| Low pulse duration | 20.01 | 0.7701 | 14.36 | 0.6426 | | 28.2% | 16.6% |
| High pulse count | 3.306 | 0.7116 | 3.237 | 0.8602 | | 2.1% | 20.9% |
| High pulse duration | 2.829 | 0.8083 | 5.143 | 1.554 | | 81.8% | 92.3% |
| | | | | | Average | 39.6% | 49.8% |
| | | | | | Score | 1 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 135.7 | 0.7785 | 233.1 | 1.1 | | 71.8% | 41.3% |
| Fall rate | -51.97 | -0.7456 | -81.76 | -1.05 | | 57.3% | 40.8% |
| Number of reversals | 91.97 | 0.1391 | 102.2 | 0.1317 | | 11.1% | 5.3% |
| | | | | | Average | 46.7% | 29.1% |
| | | | | | Score | 1 | 0 |

| | |
|---|---|
| Total Point | 9 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 8.10 DHRAM results at USGS 08167500 (Control Point CP02)

| Control Point: | CP02(USGS) | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1934-1973 | | 1974-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 255.3 | 1.281 | 347.7 | 1.040 | | 36.2% | 18.8% |
| February | 292.9 | 1.17 | 458.6 | 1.506 | | 56.6% | 28.7% |
| March | 272.5 | 1.041 | 502.2 | 1.188 | | 84.3% | 14.1% |
| April | 313.7 | 1.063 | 499.2 | 1.123 | | 59.1% | 5.6% |
| May | 456.5 | 1.11 | 552.5 | 0.961 | | 21.0% | 13.4% |
| June | 374.6 | 1.723 | 789.0 | 1.787 | | 110.6% | 3.7% |
| July | 154.4 | 1.301 | 712.2 | 2.405 | | 361.3% | 84.9% |
| August | 162.8 | 2.052 | 413.3 | 2.220 | | 153.9% | 8.2% |
| September | 343.9 | 2.081 | 278.0 | 1.022 | | 19.2% | 50.9% |
| October | 322.3 | 1.32 | 414.3 | 1.042 | | 28.5% | 21.1% |
| November | 202.3 | 1.045 | 421.7 | 1.398 | | 108.5% | 33.8% |
| December | 219.5 | 0.9134 | 424.2 | 1.850 | | 93.3% | 102.5% |
| | | | | | Average | 94.4% | 32.1% |
| | | | | | Score | 3 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 37.46 | 0.9507 | 74.9 | 0.7801 | | 99.9% | 17.9% |
| 3-day minimum | 38.39 | 0.9501 | 76.91 | 0.7762 | | 100.3% | 18.3% |
| 7-day minimum | 40.12 | 0.9429 | 79.12 | 0.7721 | | 97.2% | 18.1% |
| 30-day minimum | 49.22 | 0.8942 | 90.77 | 0.7479 | | 84.4% | 16.4% |
| 90-day minimum | 81.35 | 0.8494 | 137 | 0.7407 | | 68.4% | 12.8% |
| 1-day maximum | 9490 | 1.407 | 15880 | 1.22 | | 67.3% | 13.3% |
| 3-day maximum | 5152 | 1.176 | 9326 | 1.312 | | 81.0% | 11.6% |
| 7-day maximum | 2859 | 1.033 | 5352 | 1.314 | | 87.2% | 27.2% |
| 30-day maximum | 1114 | 0.9387 | 2039 | 1.113 | | 83.0% | 18.6% |
| 90-day maximum | 609.7 | 0.8131 | 1068 | 0.9379 | | 75.2% | 15.3% |
| | | | | | Average | 84.4% | 16.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 211.1 | 0.1754 | 223.3 | 0.2165 | | 5.8% | 23.4% |
| Date of maximum | 178.3 | 0.2395 | 193.9 | 0.2592 | | 8.7% | 8.2% |
| | | | | | Average | 7.3% | 15.8% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.744 | 0.9742 | 2 | 1.789 | | 46.6% | 83.6% |
| Low pulse duration | 23.34 | 0.7895 | 22.11 | 0.5101 | | 5.3% | 35.4% |
| High pulse count | 3.333 | 0.8688 | 3.634 | 0.852 | | 9.0% | 1.9% |
| High pulse duration | 2.626 | 0.5838 | 4.684 | 0.9653 | | 78.4% | 65.3% |
| | | | | | Average | 34.8% | 46.6% |
| | | | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 282.8 | 1.013 | 380.5 | 1.059 | | 34.5% | 4.5% |
| Fall rate | -87.27 | -1.038 | -120 | -0.9673 | | 37.5% | 6.8% |
| Number of reversals | 74.49 | 0.173 | 90.95 | 0.1511 | | 22.1% | 12.7% |
| | | | | | Average | 31.4% | 8.0% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 7 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 8.11 DHRAM results at USGS 08171000 (Control Point CP08)

| Control Point: | CP08USGS) | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1934-1973 | | 1974-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 120.6 | 1.644 | 135.1 | 1.059 | | 12.0% | 35.6% |
| February | 146.8 | 1.31 | 185.2 | 1.369 | | 26.2% | 4.5% |
| March | 134.8 | 1.117 | 194.0 | 1.117 | | 43.9% | 0.0% |
| April | 158.9 | 1.152 | 177.1 | 1.075 | | 11.5% | 6.7% |
| May | 191.6 | 1.229 | 190.0 | 0.799 | | 0.8% | 35.0% |
| June | 148.4 | 1.197 | 300.1 | 1.619 | | 102.2% | 35.3% |
| July | 67.3 | 1.409 | 226.2 | 2.273 | | 236.0% | 61.3% |
| August | 38.7 | 0.7887 | 76.9 | 1.183 | | 98.7% | 50.0% |
| September | 108.3 | 2.182 | 80.2 | 0.979 | | 25.9% | 55.1% |
| October | 93.8 | 1.562 | 156.7 | 1.610 | | 67.0% | 3.1% |
| November | 82.3 | 1.331 | 192.6 | 1.875 | | 134.1% | 40.9% |
| December | 98.1 | 1.191 | 160.3 | 1.589 | | 63.3% | 33.4% |
| | | | | | Average | 68.5% | 30.1% |
| | | | | | Score | 3 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 17.87 | 0.7196 | 29.07 | 0.6189 | | 62.7% | 14.0% |
| 3-day minimum | 18.21 | 0.7113 | 29.74 | 0.6174 | | 63.3% | 13.2% |
| 7-day minimum | 18.79 | 0.6984 | 30.64 | 0.6156 | | 63.1% | 11.9% |
| 30-day minimum | 22.04 | 0.6715 | 34.77 | 0.6097 | | 57.8% | 9.2% |
| 90-day minimum | 31.59 | 0.7558 | 49.6 | 0.6978 | | 57.0% | 7.7% |
| 1-day maximum | 4314 | 1.467 | 5864 | 1.191 | | 35.9% | 18.8% |
| 3-day maximum | 2084 | 1.2 | 3044 | 1.187 | | 46.1% | 1.1% |
| 7-day maximum | 1192 | 1.06 | 1838 | 1.159 | | 54.2% | 9.3% |
| 30-day maximum | 474.6 | 0.8429 | 746.2 | 0.9949 | | 57.2% | 18.0% |
| 90-day maximum | 261.4 | 0.7883 | 382.5 | 0.8479 | | 46.3% | 7.6% |
| | | | | | Average | 54.4% | 11.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 224.9 | 0.2766 | 215.3 | 0.3331 | | 4.3% | 20.4% |
| Date of maximum | 176.6 | 0.2451 | 191.7 | 0.2803 | | 8.6% | 14.4% |
| | | | | | Average | 6.4% | 17.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.744 | 1.311 | 2.171 | 1.739 | | 42.0% | 32.6% |
| Low pulse duration | 23.64 | 0.8518 | 13.92 | 0.6313 | | 41.1% | 25.9% |
| High pulse count | 3.308 | 0.9689 | 3.415 | 0.8073 | | 3.2% | 16.7% |
| High pulse duration | 2.54 | 0.6942 | 4.054 | 0.8692 | | 59.6% | 25.2% |
| | | | | | Average | 36.5% | 25.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 168 | 1.093 | 165.3 | 1.126 | | 1.6% | 3.0% |
| Fall rate | -46.13 | -1.028 | -47.59 | -0.9882 | | 3.2% | 3.9% |
| Number of reversals | 68.49 | 0.1384 | 92.54 | 0.1504 | | 35.1% | 8.7% |
| | | | | | Average | 13.3% | 5.2% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 6 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 8.12 DHRAM results at USGS 08172000 (Control Point CP10)

| Control Point: | CP10(USGS) | Period: | 1940-2013 | | | |
|---|---|---|---|---|---|---|
| IHA statistics group | 1940-1975 | | 1976-2013 | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | |
| January | 345.1 | 1.143 | 422.6 | 0.851 | 22.5% | 25.6% |
| February | 423.0 | 0.9228 | 480.2 | 1.220 | 13.5% | 32.2% |
| March | 354.4 | 0.7754 | 482.3 | 1.030 | 36.1% | 32.8% |
| April | 457.7 | 0.8866 | 451.5 | 0.876 | 1.4% | 1.2% |
| May | 545.1 | 0.9969 | 473.0 | 0.725 | 13.2% | 27.2% |
| June | 452.4 | 0.8071 | 701.0 | 1.444 | 55.0% | 78.9% |
| July | 261.8 | 0.9448 | 497.4 | 1.681 | 90.0% | 77.9% |
| August | 188.6 | 0.5873 | 253.0 | 0.923 | 34.1% | 57.1% |
| September | 311.1 | 1.062 | 258.6 | 0.651 | 16.9% | 38.7% |
| October | 348.6 | 1.164 | 463.0 | 1.941 | 32.8% | 66.8% |
| November | 322.3 | 0.9056 | 543.7 | 1.647 | 68.7% | 81.9% |
| December | 314.7 | 0.7869 | 468.7 | 1.365 | 48.9% | 73.5% |
| | | | | Average | 36.1% | 49.5% |
| | | | | Score | 1 | 1 |
| Parameter Group #2 | | | | | | |
| 1-day minimum | 115 | 0.4386 | 128.6 | 0.3997 | 11.8% | 8.9% |
| 3-day minimum | 121.1 | 0.4188 | 132.8 | 0.3829 | 9.7% | 8.6% |
| 7-day minimum | 124.8 | 0.4127 | 136.5 | 0.3796 | 9.4% | 8.0% |
| 30-day minimum | 136.3 | 0.4231 | 147.5 | 0.3888 | 8.2% | 8.1% |
| 90-day minimum | 164.4 | 0.4914 | 178.2 | 0.4864 | 8.4% | 1.0% |
| 1-day maximum | 8907 | 0.7921 | 11360 | 1.431 | 27.5% | 80.7% |
| 3-day maximum | 4906 | 0.751 | 6760 | 1.255 | 37.8% | 67.1% |
| 7-day maximum | 2758 | 0.7541 | 4120 | 1.159 | 49.4% | 53.7% |
| 30-day maximum | 1121 | 0.6626 | 1714 | 0.9609 | 52.9% | 45.0% |
| 90-day maximum | 668 | 0.6222 | 914.7 | 0.8019 | 36.9% | 28.9% |
| | | | | Average | 25.2% | 31.0% |
| | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | |
| Date of minimum | 219 | 0.2716 | 214.9 | 0.2845 | 1.9% | 4.7% |
| Date of maximum | 178.9 | 0.221 | 186.1 | 0.2911 | 4.0% | 31.7% |
| | | | | Average | 2.9% | 18.2% |
| | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | |
| Low pulse count | 5.139 | 1.353 | 3.605 | 1.382 | 29.9% | 2.1% |
| Low pulse duration | 18.58 | 0.8272 | 20.38 | 0.6991 | 9.7% | 15.5% |
| High pulse count | 4.833 | 0.7361 | 4.342 | 0.9154 | 10.2% | 24.4% |
| High pulse duration | 2.185 | 0.448 | 3.982 | 0.7598 | 82.2% | 69.6% |
| | | | | Average | 33.0% | 27.9% |
| | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | |
| Rise rate | 267.4 | 0.8036 | 299.5 | 1.201 | 12.0% | 49.5% |
| Fall rate | -106.2 | -0.654 | -93.07 | -0.9613 | 12.4% | 47.0% |
| Number of reversals | 123.1 | 0.3753 | 107.5 | 0.2018 | 12.7% | 46.2% |
| | | | | Average | 12.3% | 47.6% |
| | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 2 |
| Classification | 2 |
| note: | Low risk of impact |

Table 8.13 DHRAM results at USGS 08176500 (Control Point CP15)

| Control Point: | CP15(USGS) | Period: | 1935-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1935-1963 | | 1964-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1356.0 | 0.8342 | 1897.0 | 0.961 | | 39.9% | 15.2% |
| February | 1635.0 | 1.042 | 2141.0 | 1.196 | | 30.9% | 14.8% |
| March | 1430.0 | 0.8008 | 2005.0 | 0.883 | | 40.2% | 10.2% |
| April | 1793.0 | 0.8691 | 2201.0 | 0.981 | | 22.8% | 12.8% |
| May | 2539.0 | 1.097 | 2759.0 | 0.932 | | 8.7% | 15.0% |
| June | 2088.0 | 0.9867 | 2996.0 | 1.319 | | 43.5% | 33.7% |
| July | 1939.0 | 1.827 | 2045.0 | 1.482 | | 5.5% | 18.9% |
| August | 692.5 | 0.645 | 1269.0 | 1.073 | | 83.2% | 66.4% |
| September | 1469.0 | 1.024 | 1856.0 | 1.234 | | 26.3% | 20.5% |
| October | 1742.0 | 1.269 | 2167.0 | 2.044 | | 24.4% | 61.1% |
| November | 1521.0 | 1.201 | 2236.0 | 1.351 | | 47.0% | 12.5% |
| December | 1269.0 | 0.8799 | 1892.0 | 1.096 | | 49.1% | 24.6% |
| | | | | | Average | 35.1% | 25.5% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 376.7 | 0.6008 | 489.2 | 0.562 | | 29.9% | 6.5% |
| 3-day minimum | 413.8 | 0.578 | 516.2 | 0.5476 | | 24.7% | 5.3% |
| 7-day minimum | 437.6 | 0.5735 | 538.9 | 0.5328 | | 23.1% | 7.1% |
| 30-day minimum | 488.8 | 0.5625 | 601.6 | 0.5207 | | 23.1% | 7.4% |
| 90-day minimum | 655.2 | 0.5804 | 770.3 | 0.539 | | 17.6% | 7.1% |
| 1-day maximum | 24430 | 1.072 | 29520 | 1.552 | | 20.8% | 44.8% |
| 3-day maximum | 20060 | 1.075 | 24270 | 1.393 | | 21.0% | 29.6% |
| 7-day maximum | 13820 | 0.9815 | 16740 | 1.178 | | 21.1% | 20.0% |
| 30-day maximum | 5534 | 0.8567 | 7249 | 0.9208 | | 31.0% | 7.5% |
| 90-day maximum | 3136 | 0.7578 | 4188 | 0.7898 | | 33.5% | 4.2% |
| | | | | | Average | 24.6% | 13.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 222.4 | 0.2196 | 224.4 | 0.2802 | | 0.9% | 27.6% |
| Date of maximum | 179.7 | 0.2275 | 186 | 0.2881 | | 3.5% | 26.6% |
| | | | | | Average | 2.2% | 27.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.379 | 1.105 | 4.64 | 1.287 | | 13.7% | 16.5% |
| Low pulse duration | 16.63 | 1.225 | 13.94 | 1.205 | | 16.2% | 1.6% |
| High pulse count | 4.034 | 0.8207 | 4.76 | 0.7728 | | 18.0% | 5.8% |
| High pulse duration | 4.024 | 0.4154 | 6.021 | 0.6892 | | 49.6% | 65.9% |
| | | | | | Average | 24.4% | 22.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 518.8 | 0.8176 | 550 | 0.8987 | | 6.0% | 9.9% |
| Fall rate | -359.9 | -0.7243 | -357.4 | -0.8588 | | 0.7% | 18.6% |
| Number of reversals | 154.8 | 0.1571 | 144.1 | 0.1914 | | 6.9% | 21.8% |
| | | | | | Average | 4.5% | 16.8% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 1 |
| Classification | | 2 |
| note: | Low risk of impact | |

## Table 8.14 DHRAM results at USGS 08186000 (Control Point CP35)

| Control Point: | CP35(USGS) | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | 1934-1972 | | 1973-2013 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 97.9 | 2.677 | 97.3 | 1.331 | | 0.6% | 50.3% |
| February | 91.7 | 1.746 | 141.4 | 2.024 | | 54.2% | 15.9% |
| March | 50.8 | 0.8508 | 109.9 | 1.506 | | 116.3% | 77.0% |
| April | 147.4 | 1.704 | 154.6 | 1.802 | | 4.9% | 5.8% |
| May | 258.0 | 1.666 | 188.8 | 1.379 | | 26.8% | 17.2% |
| June | 166.7 | 1.669 | 320.9 | 1.799 | | 92.5% | 7.8% |
| July | 96.4 | 2.653 | 212.9 | 2.869 | | 121.0% | 8.1% |
| August | 60.1 | 2.57 | 73.1 | 1.880 | | 21.7% | 26.8% |
| September | 178.3 | 2.032 | 153.1 | 1.979 | | 14.1% | 2.6% |
| October | 104.0 | 1.614 | 222.0 | 2.506 | | 113.5% | 55.3% |
| November | 72.3 | 1.516 | 204.7 | 2.076 | | 183.0% | 36.9% |
| December | 72.2 | 1.413 | 137.9 | 2.490 | | 90.9% | 76.2% |
| | | | | | Average | 70.0% | 31.7% |
| | | | | | Score | 3 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 8.821 | 0.6038 | 18.44 | 0.7547 | | 109.0% | 25.0% |
| 3-day minimum | 9.137 | 0.5863 | 18.87 | 0.738 | | 106.5% | 25.9% |
| 7-day minimum | 9.604 | 0.5543 | 19.55 | 0.7216 | | 103.6% | 30.2% |
| 30-day minimum | 11.46 | 0.5388 | 22.85 | 0.6808 | | 99.4% | 26.4% |
| 90-day minimum | 18.89 | 0.6543 | 32.29 | 0.6552 | | 70.9% | 0.1% |
| 1-day maximum | 6853 | 0.8522 | 8005 | 1.146 | | 16.8% | 34.5% |
| 3-day maximum | 4173 | 0.8891 | 4950 | 1.169 | | 18.6% | 31.5% |
| 7-day maximum | 2299 | 0.9094 | 2868 | 1.161 | | 24.7% | 27.7% |
| 30-day maximum | 673 | 0.8573 | 946.7 | 1.06 | | 40.7% | 23.6% |
| 90-day maximum | 314.1 | 0.8626 | 414.6 | 0.9568 | | 32.0% | 10.9% |
| | | | | | Average | 62.2% | 23.6% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 214.5 | 0.1574 | 228.7 | 0.1786 | | 6.6% | 13.5% |
| Date of maximum | 177.7 | 0.2103 | 213.4 | 0.24 | | 20.1% | 14.1% |
| | | | | | Average | 13.4% | 13.8% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 6.359 | 0.9016 | 1.878 | 1.507 | | 70.5% | 67.1% |
| Low pulse duration | 12.62 | 0.6168 | 16.32 | 0.7075 | | 29.3% | 14.7% |
| High pulse count | 4.051 | 0.7094 | 4.146 | 0.8045 | | 2.3% | 13.4% |
| High pulse duration | 1.973 | 0.422 | 2.668 | 0.6985 | | 35.2% | 65.5% |
| | | | | | Average | 34.3% | 40.2% |
| | | | | | Score | 0 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 236.5 | 0.866 | 221.3 | 1.035 | | 6.4% | 19.5% |
| Fall rate | -100.7 | -0.7555 | -103.8 | -1.202 | | 3.1% | 59.1% |
| Number of reversals | 83.79 | 0.1745 | 85.27 | 0.1853 | | 1.8% | 6.2% |
| | | | | | Average | 3.8% | 28.3% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 7 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

### 8.1.2 Assessment of Naturalized versus Simulated Regulated Flows

Daily naturalized flows are considered un-impacted flows, and regulated flows, simulated by daily WRAP models under a full authorized water use scenarios, are considered impacted flows at the control points that have the environmental flow standards. The alterations between both the flow regimes on the flows are assessed by the DHRAM method. In fact, even though the environmental flow standards were established at each control point, these cannot restore flow regimes because other water rights have senior priorities to the environmental flow standards at the control points. Thus, the environmental flow standards restrict only future water uses. In other words, the DHRAM analysis theoretically indicates how much the flow regimes of the regulated flows are different from the naturalized flows under a full authorized water use condition.

*Sabine River Basin*

The period-of-analysis of the Sabine WAM is from 1940 to 2013. The Sabine WAM has the five control points that have environmental flow standards, but the DHRAM analyses are performed at the four control points for the comparison with the results with the USGS recorded flows.

Table 8.15 presents the result of the analysis at the control point BSBS. The means and coefficients of variance of both flows at the five parameter groups are almost identical. The analysis yields a total of 0 impact points and a corresponding DHRAM class of 1. This means that there are no human influences on the river flow.

The result of the analysis at the control point SRGW is as shown in Table 8.16. The monthly regulated flows decrease than the naturalized flows. The minimum and maximum flows of the regulated flow also decrease than the naturalized flow. Flow timing parameters of both flows are totally different. The analysis yields a total of 9 impact points and a corresponding DHRAM class of 3.

Table 8.17 provides the result of the analysis at the control point SRBE. The result is almost similar to the control point SRGW. The analysis yields a total of 10 impact points and a corresponding DHRAM class of 3.

Table 8.18 presents the result of the analysis at the control point SRRL.  The result also is closely similar to the control points SRGW and SRBE. The analysis yields a total of 11 impact points and a corresponding DHRAM class of 4.

*Neches River Basin*

The period-of-analysis of the Neches WAM is from 1940 to 2013. The Neches WAM has also the five control points that have environmental flow standards, but the DHRAM analyses also are performed at the four control points for the comparison with the results with the USGS recorded flows.

Table 8.19 presents the result of the analysis at the control point NENE. The monthly flows and the minimum and maximum for certain days of the regulated flow slightly decrease than the naturalized flows. Most of all, flow timings of both the flows are tremendously different The analysis yields a total of 6 impact points and a corresponding DHRAM class of 3.

The result of the analysis at the control points NERO is as shown in Table 8.20. The parameters of both the flows are nearly similar except for the parameter for flow timing. The average date of minimum of the regulated flow is put forward about 160 days than the naturalized flow. The analysis yields a total of 5 impact points and a corresponding DHRAM class of 3.

Table 8.21 presents the result of the analysis at the control points NEEV.  The monthly flows of the regulated flow decreases than the naturalized flow. The minimum and maximum flows of the regulated flow also decrease than the naturalized flow. The average dates of minimum and maximum of the regulated flow are put forward about 190 and 70 days, respectively than the naturalized flow. The analysis yields a total of 11 impact points and a corresponding DHRAM class of 4.

Table 8.22 presents the result of the analysis at the control point VIKO. The means and coefficients of variance of both the flows at the five parameter groups are almost identical. The analysis yields a total of 0 impact points and a corresponding DHRAM class of 1.

Table 8.15 DHRAM results at Control Point BSBS (Naturalized vs. Regulated Flows)

| Control Point: | BSBS | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 238.4 | 0.8167 | 233.9 | 0.8434 | | 1.9% | 3.3% |
| February | 284.5 | 0.6652 | 280.2 | 0.6911 | | 1.5% | 3.9% |
| March | 304 | 0.8101 | 299.3 | 0.8346 | | 1.5% | 3.0% |
| April | 286.3 | 0.883 | 280.9 | 0.9071 | | 1.9% | 2.7% |
| May | 283.2 | 0.8972 | 278.5 | 0.9213 | | 1.7% | 2.7% |
| June | 170.5 | 0.9918 | 163.8 | 1.035 | | 3.9% | 4.4% |
| July | 85.66 | 1.305 | 79.98 | 1.387 | | 6.6% | 6.3% |
| August | 36.92 | 0.9991 | 33.94 | 1.01 | | 8.1% | 1.1% |
| September | 59.45 | 1.452 | 55.79 | 1.533 | | 6.2% | 5.6% |
| October | 97.84 | 1.95 | 93.12 | 2.05 | | 4.8% | 5.1% |
| November | 155.7 | 1.174 | 148.9 | 1.234 | | 4.4% | 5.1% |
| December | 235.8 | 0.8424 | 230.2 | 0.8702 | | 2.4% | 3.3% |
| | | | | | Average | 3.7% | 3.9% |
| | | | | | Score | **0** | **0** |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 7.218 | 1.005 | 6.301 | 1.007 | | 12.7% | 0.2% |
| 3-day minimum | 7.844 | 0.9778 | 6.935 | 0.9662 | | 11.6% | 1.2% |
| 7-day minimum | 8.934 | 0.9385 | 7.922 | 0.9189 | | 11.3% | 2.1% |
| 30-day minimum | 17.35 | 0.6844 | 15.92 | 0.6635 | | 8.2% | 3.1% |
| 90-day minimum | 36.33 | 0.7197 | 33.31 | 0.7256 | | 8.3% | 0.8% |
| 1-day maximum | 2413 | 0.5878 | 2397 | 0.5941 | | 0.7% | 1.1% |
| 3-day maximum | 2137 | 0.6097 | 2123 | 0.6154 | | 0.7% | 0.9% |
| 7-day maximum | 1505 | 0.6067 | 1497 | 0.6134 | | 0.5% | 1.1% |
| 30-day maximum | 660.2 | 0.509 | 656.3 | 0.5179 | | 0.6% | 1.7% |
| 90-day maximum | 400.7 | 0.4952 | 396.5 | 0.5079 | | 1.0% | 2.6% |
| | | | | | Average | 5.6% | 1.5% |
| | | | | | Score | **0** | **0** |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 204.7 | 0.2539 | 205.6 | 0.2416 | | 0.4% | 4.8% |
| Date of maximum | 148.4 | 0.3181 | 148.4 | 0.318 | | 0.0% | 0.0% |
| | | | | | Average | 0.2% | 2.4% |
| | | | | | Score | **0** | **0** |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8.635 | 0.5587 | 9.122 | 0.5065 | | 5.6% | 9.3% |
| Low pulse duration | 11.07 | 0.5347 | 10.17 | 0.482 | | 8.1% | 9.9% |
| High pulse count | 5.676 | 0.5855 | 5.554 | 0.5841 | | 2.1% | 0.2% |
| High pulse duration | 4.625 | 0.3475 | 4.688 | 0.3469 | | 1.4% | 0.2% |
| | | | | | Average | 4.3% | 4.9% |
| | | | | | Score | **0** | **0** |
| Parameter Group #5 | | | | | | | |
| Rise rate | 107.8 | 0.6271 | 102.8 | 0.6443 | | 4.6% | 2.7% |
| Fall rate | -36.28 | -0.5553 | -35.97 | -0.5634 | | 0.9% | 1.5% |
| Number of reversals | 98.69 | 0.156 | 101.8 | 0.1643 | | 3.2% | 5.3% |
| | | | | | Average | 2.9% | 3.2% |
| | | | | | Score | **0** | **0** |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 8.16 DHRAM results at Control Point SRGW (Naturalized vs. Regulated Flows)

| Control Point: | SRGW | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 50 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 2425 | 0.9114 | 1680 | 0.9105 | | 30.7% | 0.1% |
| February | 2988 | 0.8102 | 1964 | 0.8478 | | 34.3% | 4.6% |
| March | 3184 | 0.8404 | 2144 | 0.934 | | 32.7% | 11.1% |
| April | 3140 | 1.137 | 2171 | 1.386 | | 30.9% | 21.9% |
| May | 3899 | 1.058 | 2674 | 1.123 | | 31.4% | 6.1% |
| June | 2442 | 1.221 | 1680 | 1.366 | | 31.2% | 11.9% |
| July | 801.1 | 1.719 | 515.3 | 1.657 | | 35.7% | 3.6% |
| August | 270 | 1.56 | 174.2 | 1.864 | | 35.5% | 19.5% |
| September | 480.3 | 1.646 | 287.7 | 1.569 | | 40.1% | 4.7% |
| October | 1184 | 2.126 | 658.2 | 2.015 | | 44.4% | 5.2% |
| November | 1758 | 1.341 | 1143 | 1.469 | | 35.0% | 9.5% |
| December | 2645 | 1.058 | 1751 | 1.112 | | 33.8% | 5.1% |
| | | | | | Average | 34.6% | 8.6% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 35.75 | 1.237 | 0.08108 | 8.602 | | 99.8% | 595.4% |
| 3-day minimum | 37.57 | 1.22 | 3.928 | 2.636 | | 89.5% | 116.1% |
| 7-day minimum | 41.84 | 1.189 | 14.97 | 1.781 | | 64.2% | 49.8% |
| 30-day minimum | 82.65 | 1.085 | 45.03 | 1.232 | | 45.5% | 13.5% |
| 90-day minimum | 247.8 | 0.9685 | 150.4 | 0.9816 | | 39.3% | 1.4% |
| 1-day maximum | 16970 | 0.6045 | 13190 | 0.7146 | | 22.3% | 18.2% |
| 3-day maximum | 15940 | 0.6093 | 11650 | 0.7449 | | 26.9% | 22.3% |
| 7-day maximum | 14330 | 0.6179 | 10040 | 0.7607 | | 29.9% | 23.1% |
| 30-day maximum | 8461 | 0.5885 | 5786 | 0.6781 | | 31.6% | 15.2% |
| 90-day maximum | 4929 | 0.5464 | 3333 | 0.6166 | | 32.4% | 12.8% |
| | | | | | Average | 48.1% | 86.8% |
| | | | | | Score | 1 | 1 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 255.4 | 0.1017 | 87.91 | 0.2015 | | 65.6% | 98.1% |
| Date of maximum | 162.1 | 0.3099 | 162.5 | 0.3037 | | 0.2% | 2.0% |
| | | | | | Average | 32.9% | 50.1% |
| | | | | | Score | 2 | 1 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.946 | 0.4854 | 9.784 | 0.3546 | | 147.9% | 26.9% |
| Low pulse duration | 26.22 | 0.7151 | 10.55 | 0.7223 | | 59.8% | 1.0% |
| High pulse count | 2.919 | 0.6728 | 4.662 | 0.6423 | | 59.7% | 4.5% |
| High pulse duration | 12.68 | 0.5818 | 6.875 | 0.6044 | | 45.8% | 3.9% |
| | | | | | Average | 78.3% | 9.1% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.4 | 0.5222 | 405.4 | 0.4825 | | 22.7% | 7.6% |
| Fall rate | -194.4 | -0.5095 | -249.2 | -0.471 | | 28.2% | 7.6% |
| Number of reversals | 56.82 | 0.1528 | 118.7 | 0.1381 | | 108.9% | 9.6% |
| | | | | | Average | 53.3% | 8.3% |
| | | | | | Score | 1 | 0 |

| | |
|---|---|
| Total Point | 9 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 8.17 DHRAM results at Control Point SRBE (Naturalized vs. Regulated Flows)

| Control Point: | SRBE | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 50 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 3514 | 0.8648 | 2543 | 0.9011 | | 27.6% | 4.2% |
| February | 4193 | 0.7109 | 2972 | 0.7669 | | 29.1% | 7.9% |
| March | 4257 | 0.7737 | 3009 | 0.8621 | | 29.3% | 11.4% |
| April | 4005 | 1.036 | 2901 | 1.289 | | 27.6% | 24.4% |
| May | 4904 | 1.015 | 3442 | 1.066 | | 29.8% | 5.0% |
| June | 3215 | 1.085 | 2315 | 1.22 | | 28.0% | 12.4% |
| July | 1117 | 1.389 | 725.6 | 1.436 | | 35.0% | 3.4% |
| August | 424 | 1.401 | 270.8 | 1.689 | | 36.1% | 20.6% |
| September | 663.5 | 1.541 | 410.2 | 1.515 | | 38.2% | 1.7% |
| October | 1471 | 2.012 | 883.9 | 2.006 | | 39.9% | 0.3% |
| November | 2325 | 1.23 | 1572 | 1.327 | | 32.4% | 7.9% |
| December | 3384 | 0.9509 | 2294 | 1.011 | | 32.2% | 6.3% |
| | | | | | Average | 32.1% | 8.8% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 76.84 | 0.9809 | 3.565 | 3.533 | | 95.4% | 260.2% |
| 3-day minimum | 80.32 | 0.9697 | 22.1 | 1.33 | | 72.5% | 37.2% |
| 7-day minimum | 88.92 | 0.9438 | 39.47 | 1.114 | | 55.6% | 18.0% |
| 30-day minimum | 150.3 | 0.9023 | 78.53 | 0.9691 | | 47.8% | 7.4% |
| 90-day minimum | 399.5 | 0.9217 | 240.3 | 0.9706 | | 39.8% | 5.3% |
| 1-day maximum | 17110 | 0.5888 | 13710 | 0.6496 | | 19.9% | 10.3% |
| 3-day maximum | 16510 | 0.5971 | 12850 | 0.6596 | | 22.2% | 10.5% |
| 7-day maximum | 15230 | 0.6145 | 11460 | 0.6792 | | 24.8% | 10.5% |
| 30-day maximum | 10060 | 0.582 | 7260 | 0.6445 | | 27.8% | 10.7% |
| 90-day maximum | 6261 | 0.5175 | 4461 | 0.5787 | | 28.7% | 11.8% |
| | | | | | Average | 43.4% | 38.2% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 252.3 | 0.1018 | 99.58 | 0.2598 | | 60.5% | 155.2% |
| Date of maximum | 153.7 | 0.3076 | 149.3 | 0.3004 | | 2.9% | 2.3% |
| | | | | | Average | 31.7% | 78.8% |
| | | | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.527 | 0.5828 | 8.473 | 0.457 | | 140.2% | 21.6% |
| Low pulse duration | 33.34 | 0.8444 | 12.69 | 0.8744 | | 61.9% | 3.6% |
| High pulse count | 3.054 | 0.7085 | 4.541 | 0.6928 | | 48.7% | 2.2% |
| High pulse duration | 14.47 | 0.5802 | 8.268 | 0.5774 | | 42.9% | 0.5% |
| | | | | | Average | 73.4% | 7.0% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.4 | 0.5169 | 408.8 | 0.4806 | | 23.7% | 7.0% |
| Fall rate | -202 | -0.5119 | -269.3 | -0.4645 | | 33.3% | 9.3% |
| Number of reversals | 56.39 | 0.1386 | 115.5 | 0.1326 | | 104.8% | 4.3% |
| | | | | | Average | 54.0% | 6.9% |
| | | | | | Score | 1 | 0 |

| | | |
|---|---|---|
| Total Point | | 10 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 8.18 DHRAM results at Control Point SRRL (Naturalized vs. Regulated Flows)

| Control Point: | SRRL | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 50 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 13120 | 0.7497 | 8407 | 1.084 | | 35.9% | 44.6% |
| February | 14690 | 0.578 | 10120 | 0.7961 | | 31.1% | 37.7% |
| March | 13140 | 0.6133 | 9166 | 0.8048 | | 30.2% | 31.2% |
| April | 12510 | 0.7303 | 8606 | 0.9995 | | 31.2% | 36.9% |
| May | 11740 | 0.9706 | 7571 | 1.331 | | 35.5% | 37.1% |
| June | 8696 | 0.925 | 5773 | 1.289 | | 33.6% | 39.4% |
| July | 4722 | 1.278 | 3048 | 1.724 | | 35.5% | 34.9% |
| August | 2270 | 1.13 | 1407 | 1.34 | | 38.0% | 18.6% |
| September | 2523 | 1.212 | 1509 | 1.447 | | 40.2% | 19.4% |
| October | 4069 | 1.49 | 2051 | 1.695 | | 49.6% | 13.8% |
| November | 6420 | 1.156 | 3324 | 1.629 | | 48.2% | 40.9% |
| December | 10280 | 0.8322 | 5894 | 1.176 | | 42.7% | 41.3% |
| | | | | | Average | 37.6% | 33.0% |
| | | | | | Score | 1 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 646.9 | 0.74 | 13.47 | 3.81 | | 97.9% | 414.9% |
| 3-day minimum | 660.6 | 0.7401 | 51.02 | 1.893 | | 92.3% | 155.8% |
| 7-day minimum | 692.8 | 0.7343 | 155.3 | 1.512 | | 77.6% | 105.9% |
| 30-day minimum | 926.3 | 0.7261 | 403.8 | 0.8313 | | 56.4% | 14.5% |
| 90-day minimum | 1768 | 0.7263 | 871.2 | 0.724 | | 50.7% | 0.3% |
| 1-day maximum | 45300 | 0.5594 | 36630 | 0.6513 | | 19.1% | 16.4% |
| 3-day maximum | 42360 | 0.5417 | 33770 | 0.6425 | | 20.3% | 18.6% |
| 7-day maximum | 37480 | 0.5058 | 29230 | 0.6407 | | 22.0% | 26.7% |
| 30-day maximum | 25840 | 0.4848 | 19610 | 0.6636 | | 24.1% | 36.9% |
| 90-day maximum | 17500 | 0.44 | 12450 | 0.6396 | | 28.9% | 45.4% |
| | | | | | Average | 48.9% | 83.5% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 261.6 | 0.1064 | 79.39 | 0.2629 | | 69.7% | 147.1% |
| Date of maximum | 65.57 | 0.2011 | 74.54 | 0.212 | | 13.7% | 5.4% |
| | | | | | Average | 41.7% | 76.3% |
| | | | | | Score | 3 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.446 | 0.602 | 7.73 | 0.4549 | | 216.0% | 24.4% |
| Low pulse duration | 44.17 | 0.6551 | 13.11 | 0.8384 | | 70.3% | 28.0% |
| High pulse count | 3.176 | 0.6961 | 3.068 | 0.7405 | | 3.4% | 6.4% |
| High pulse duration | 14.4 | 0.6013 | 13.51 | 0.6782 | | 6.2% | 12.8% |
| | | | | | Average | 74.0% | 17.9% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 947.3 | 0.5524 | 871.9 | 0.5648 | | 8.0% | 2.2% |
| Fall rate | -479.8 | -0.5361 | -554.2 | -0.5134 | | 15.5% | 4.2% |
| Number of reversals | 58.31 | 0.153 | 84.61 | 0.1606 | | 45.1% | 5.0% |
| | | | | | Average | 22.9% | 3.8% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 11 |
| Classification | | 4 |
| note: | High risk of impact | |

Table 8.19 DHRAM results at Control Point NENE (Naturalized vs. Regulated Flows)

Control Point: NENE Period: 1940-2013

| IHA statistics group | Naturalized | | Regulated, 2009 | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1015 | 0.8536 | 515 | 1.174 | | 49.3% | 37.5% |
| February | 1239 | 0.7049 | 691.9 | 0.9881 | | 44.2% | 40.2% |
| March | 1219 | 0.6986 | 691.5 | 1.072 | | 43.3% | 53.4% |
| April | 1155 | 1.074 | 683.3 | 1.441 | | 40.8% | 34.2% |
| May | 1209 | 1.056 | 661.1 | 1.38 | | 45.3% | 30.7% |
| June | 726.5 | 1.156 | 398.7 | 1.44 | | 45.1% | 24.6% |
| July | 236.9 | 1.836 | 146.4 | 1.629 | | 38.2% | 11.3% |
| August | 72.4 | 1.964 | 75.6 | 1.156 | | 4.4% | 41.1% |
| September | 212.2 | 1.812 | 115.5 | 1.305 | | 45.6% | 28.0% |
| October | 446.8 | 2.142 | 235.1 | 2.422 | | 47.4% | 13.1% |
| November | 668.5 | 1.32 | 348.2 | 1.562 | | 47.9% | 18.3% |
| December | 962.4 | 0.9138 | 432.4 | 1.075 | | 55.1% | 17.6% |
| | | | | | Average | 42.2% | 29.2% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 5.162 | 2.743 | 1.000 | 2.715 | | 80.6% | 1.0% |
| 3-day minimum | 5.946 | 2.855 | 2.216 | 1.782 | | 62.7% | 37.6% |
| 7-day minimum | 8.743 | 3.286 | 6.552 | 0.9939 | | 25.1% | 69.8% |
| 30-day minimum | 24.94 | 1.804 | 30.480 | 0.5144 | | 22.2% | 71.5% |
| 90-day minimum | 93.09 | 1.407 | 67.600 | 0.6896 | | 27.4% | 51.0% |
| 1-day maximum | 7681 | 0.6525 | 5423 | 0.765 | | 29.4% | 17.2% |
| 3-day maximum | 6887 | 0.6553 | 4565 | 0.8029 | | 33.7% | 22.5% |
| 7-day maximum | 5969 | 0.6271 | 3787 | 0.8088 | | 36.6% | 29.0% |
| 30-day maximum | 3056 | 0.5362 | 1845 | 0.7713 | | 39.6% | 43.8% |
| 90-day maximum | 1773 | 0.5009 | 1029 | 0.7476 | | 42.0% | 49.3% |
| | | | | | Average | 39.9% | 39.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 221.7 | 0.1533 | 63.16 | 0.2035 | | 71.5% | 32.7% |
| Date of maximum | 67.27 | 0.1753 | 140.6 | 0.2785 | | 109.0% | 58.9% |
| | | | | | Average | 90.3% | 45.8% |
| | | | | | Score | 3 | 1 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.324 | 0.4563 | 10.61 | 0.2773 | | 145.4% | 39.2% |
| Low pulse duration | 24.74 | 0.8672 | 9.132 | 0.7695 | | 63.1% | 11.3% |
| High pulse count | 4.635 | 0.6191 | 4.892 | 0.654 | | 5.5% | 5.6% |
| High pulse duration | 7.569 | 0.4332 | 5.111 | 0.6827 | | 32.5% | 57.6% |
| | | | | | Average | 61.6% | 28.4% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 216.8 | 0.5456 | 179.2 | 0.6231 | | 17.3% | 14.2% |
| Fall rate | -114.8 | -0.5323 | -115.5 | -0.5858 | | 0.6% | 10.1% |
| Number of reversals | 52.88 | 0.2205 | 76.28 | 0.1905 | | 44.3% | 13.6% |
| | | | | | Average | 20.7% | 12.6% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 6 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 8.20 DHRAM results at Control Point NERO (Naturalized vs. Regulated Flows)

| Control Point: | NERO | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 2009 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 3854 | 0.8892 | 3284 | 0.9706 | | 14.8% | 9.2% |
| February | 4158 | 0.7283 | 3602 | 0.8015 | | 13.4% | 10.1% |
| March | 3573 | 0.7663 | 2961 | 0.894 | | 17.1% | 16.7% |
| April | 3289 | 0.9322 | 2793 | 1.024 | | 15.1% | 9.8% |
| May | 3709 | 1.1 | 3075 | 1.227 | | 17.1% | 11.5% |
| June | 2347 | 1.105 | 1959 | 1.251 | | 16.5% | 13.2% |
| July | 1002 | 1.686 | 837 | 1.864 | | 16.5% | 10.6% |
| August | 305.2 | 1.549 | 250.4 | 1.622 | | 18.0% | 4.7% |
| September | 519.9 | 1.478 | 386.1 | 1.595 | | 25.7% | 7.9% |
| October | 1194 | 1.801 | 950.6 | 1.903 | | 20.4% | 5.7% |
| November | 2181 | 1.457 | 1823 | 1.571 | | 16.4% | 7.8% |
| December | 3072 | 1.081 | 2510 | 1.182 | | 18.3% | 9.3% |
| | | | | | Average | 17.4% | 9.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 45.64 | 1.637 | 2.203 | 6.26 | | 95.2% | 282.4% |
| 3-day minimum | 48.16 | 1.669 | 3.117 | 5.278 | | 93.5% | 216.2% |
| 7-day minimum | 53.78 | 1.666 | 6.502 | 3.249 | | 87.9% | 95.0% |
| 30-day minimum | 98.56 | 1.526 | 46.890 | 1.767 | | 52.4% | 15.8% |
| 90-day minimum | 298.9 | 1.249 | 216.200 | 1.392 | | 27.7% | 11.4% |
| 1-day maximum | 17230 | 0.6091 | 15770 | 0.6305 | | 8.5% | 3.5% |
| 3-day maximum | 15990 | 0.6048 | 14590 | 0.6364 | | 8.8% | 5.2% |
| 7-day maximum | 14270 | 0.5882 | 12850 | 0.6364 | | 10.0% | 8.2% |
| 30-day maximum | 8774 | 0.5577 | 7716 | 0.6207 | | 12.1% | 11.3% |
| 90-day maximum | 5512 | 0.5299 | 4754 | 0.6009 | | 13.8% | 13.4% |
| | | | | | Average | 41.0% | 66.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 247.2 | 0.1121 | 89.93 | 0.2799 | | 63.6% | 149.7% |
| Date of maximum | 148.8 | 0.3018 | 150.1 | 0.2998 | | 0.9% | 0.7% |
| | | | | | Average | 32.2% | 75.2% |
| | | | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.905 | 0.5227 | 4.919 | 0.4486 | | 69.3% | 14.2% |
| Low pulse duration | 35.54 | 0.7146 | 19.68 | 0.6138 | | 44.6% | 14.1% |
| High pulse count | 3.486 | 0.7919 | 3.514 | 0.7317 | | 0.8% | 7.6% |
| High pulse duration | 11.57 | 0.6183 | 11.32 | 0.7306 | | 2.2% | 18.2% |
| | | | | | Average | 29.2% | 13.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 442.7 | 0.6301 | 448 | 0.6005 | | 1.2% | 4.7% |
| Fall rate | -207.3 | -0.5878 | -227.2 | -0.551 | | 9.6% | 6.3% |
| Number of reversals | 54.27 | 0.2735 | 63.69 | 0.2097 | | 17.4% | 23.3% |
| | | | | | Average | 9.4% | 11.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 5 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 8.21 DHRAM results at Control Point NEEV (Naturalized vs. Regulated Flows)

| Control Point: | NEEV | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 2009 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 9770 | 0.8516 | 6044 | 1.047 | | 38.1% | 22.9% |
| February | 10790 | 0.6577 | 8426 | 0.9122 | | 21.9% | 38.7% |
| March | 9273 | 0.7049 | 7594 | 0.9738 | | 18.1% | 38.1% |
| April | 8424 | 0.8106 | 6024 | 1.062 | | 28.5% | 31.0% |
| May | 8684 | 1.072 | 5801 | 1.124 | | 33.2% | 4.9% |
| June | 5928 | 1.051 | 5057 | 1.38 | | 14.7% | 31.3% |
| July | 2628 | 1.362 | 2126 | 1.653 | | 19.1% | 21.4% |
| August | 998.8 | 1.151 | 642.6 | 1.51 | | 35.7% | 31.2% |
| September | 1663 | 1.381 | 745.5 | 1.695 | | 55.2% | 22.7% |
| October | 3318 | 1.822 | 1198 | 1.741 | | 63.9% | 4.4% |
| November | 5588 | 1.398 | 3019 | 1.802 | | 46.0% | 28.9% |
| December | 7953 | 0.9712 | 5126 | 1.242 | | 35.5% | 27.9% |
| | | | | | Average | 34.2% | 25.3% |
| | | | | | Score | **1** | **0** |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 200.9 | 1.223 | 1.703 | 6.52 | | 99.2% | 433.1% |
| 3-day minimum | 209.6 | 1.22 | 9.554 | 3.111 | | 95.4% | 155.0% |
| 7-day minimum | 227.9 | 1.201 | 33.33 | 2.346 | | 85.4% | 95.3% |
| 30-day minimum | 395.7 | 1.223 | 133.5 | 1.606 | | 66.3% | 31.3% |
| 90-day minimum | 900.5 | 1.015 | 377.2 | 1.193 | | 58.1% | 17.5% |
| 1-day maximum | 37530 | 0.652 | 27020 | 0.6014 | | 28.0% | 7.8% |
| 3-day maximum | 35310 | 0.6293 | 25390 | 0.5739 | | 28.1% | 8.8% |
| 7-day maximum | 32120 | 0.5985 | 23360 | 0.5673 | | 27.3% | 5.2% |
| 30-day maximum | 20880 | 0.5489 | 16150 | 0.6132 | | 22.7% | 11.7% |
| 90-day maximum | 13450 | 0.5012 | 10110 | 0.6488 | | 24.8% | 29.4% |
| | | | | | Average | 53.5% | 79.5% |
| | | | | | Score | **1** | **0** |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 259.4 | 0.1293 | 70.57 | 0.2688 | | 72.8% | 107.9% |
| Date of maximum | 141.2 | 0.2954 | 74.97 | 0.1803 | | 46.9% | 39.0% |
| | | | | | Average | 59.9% | 73.4% |
| | | | | | Score | **3** | **3** |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.514 | 0.4429 | 8.162 | 0.5905 | | 224.7% | 33.3% |
| Low pulse duration | 41.43 | 0.9228 | 17.7 | 1.878 | | 57.3% | 103.5% |
| High pulse count | 2.608 | 0.7558 | 3.122 | 0.7882 | | 19.7% | 4.3% |
| High pulse duration | 16.94 | 0.6418 | 15.09 | 0.7559 | | 10.9% | 17.8% |
| | | | | | Average | 78.1% | 39.7% |
| | | | | | Score | **2** | **1** |
| Parameter Group #5 | | | | | | | |
| Rise rate | 677.1 | 0.5428 | 682.7 | 0.542 | | 0.8% | 0.1% |
| Fall rate | -386.8 | -0.5466 | -554 | -0.6975 | | 43.2% | 27.6% |
| Number of reversals | 45.53 | 0.19 | 82.43 | 0.2293 | | 81.0% | 20.7% |
| | | | | | Average | 41.7% | 16.1% |
| | | | | | Score | **0** | **0** |

| | |
|---|---|
| Total Point | 11 |
| Classification | 4 |
| note: | High risk of impact |

Table 8.22 DHRAM results at Control Point VIKO (Naturalized vs. Regulated Flows)

| Control Point: | VIKO | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated, 2009 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1381 | 0.8871 | 1381 | 0.8874 | | 0.0% | 0.0% |
| February | 1395 | 0.7546 | 1395 | 0.7549 | | 0.0% | 0.0% |
| March | 1046 | 0.7362 | 1045 | 0.7367 | | 0.1% | 0.1% |
| April | 959.4 | 1.103 | 958.7 | 1.103 | | 0.1% | 0.0% |
| May | 1020 | 1.172 | 1020 | 1.172 | | 0.0% | 0.0% |
| June | 827.8 | 1.456 | 827.2 | 1.457 | | 0.1% | 0.1% |
| July | 532.5 | 1.415 | 531.6 | 1.416 | | 0.2% | 0.1% |
| August | 264.1 | 1.148 | 263.4 | 1.149 | | 0.3% | 0.1% |
| September | 398.1 | 1.492 | 397 | 1.494 | | 0.3% | 0.1% |
| October | 650.2 | 2.009 | 649.6 | 2.011 | | 0.1% | 0.1% |
| November | 968.2 | 1.409 | 967.6 | 1.41 | | 0.1% | 0.1% |
| December | 1170 | 0.9349 | 1170 | 0.9354 | | 0.0% | 0.1% |
| | | | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.135 | 2.893 | 2.095 | 2.904 | | 1.9% | 0.4% |
| 3-day minimum | 2.428 | 2.747 | 2.419 | 2.716 | | 0.4% | 1.1% |
| 7-day minimum | 3.714 | 2.704 | 3.705 | 2.687 | | 0.2% | 0.6% |
| 30-day minimum | 35.5 | 2.269 | 35.350 | 2.279 | | 0.4% | 0.4% |
| 90-day minimum | 162 | 1.094 | 161.400 | 1.098 | | 0.4% | 0.4% |
| 1-day maximum | 9326 | 0.684 | 9326 | 0.6841 | | 0.0% | 0.0% |
| 3-day maximum | 8566 | 0.6866 | 8565 | 0.6867 | | 0.0% | 0.0% |
| 7-day maximum | 7177 | 0.6383 | 7176 | 0.6383 | | 0.0% | 0.0% |
| 30-day maximum | 3488 | 0.6087 | 3488 | 0.6088 | | 0.0% | 0.0% |
| 90-day maximum | 1921 | 0.5368 | 1921 | 0.537 | | 0.0% | 0.0% |
| | | | | | Average | 0.3% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 200.1 | 0.2048 | 199.1 | 0.2099 | | 0.5% | 2.5% |
| Date of maximum | 59.78 | 0.2275 | 59.74 | 0.2275 | | 0.1% | 0.0% |
| | | | | | Average | 0.3% | 1.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.014 | 0.378 | 7.054 | 0.3826 | | 0.6% | 1.2% |
| Low pulse duration | 13.02 | 0.3544 | 13.03 | 0.3538 | | 0.1% | 0.2% |
| High pulse count | 4.595 | 0.705 | 4.608 | 0.7046 | | 0.3% | 0.1% |
| High pulse duration | 7.483 | 0.5295 | 7.461 | 0.5294 | | 0.3% | 0.0% |
| | | | | | Average | 0.3% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 305.8 | 0.5543 | 305.7 | 0.5547 | | 0.0% | 0.1% |
| Fall rate | -140.5 | -0.5584 | -140.7 | -0.5587 | | 0.1% | 0.1% |
| Number of reversals | 54.68 | 0.1635 | 54.81 | 0.1637 | | 0.2% | 0.1% |
| | | | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

*GSA River Basins*

The period-of-analysis of the GSA WAM is from 1934 to 2013. The GSA WAM has the fifteen control points that have environmental flow standards, but the DHRAM analyses also are performed at the six control points for the comparison with the results with the USGS recorded flows.

The flow regimes of both the flows are almost identical at the six control points in the GSA River Basins. The results of the analyses at the six control points are as shown in Tables 8.23 to 8.28, respectively. The DHRAM yields a total of 1 impact points at the control points CP01 and CP10, and a total of 0 impact points at the control points CP02, CP08, CP15, and CP35, respectively.

## 8.2 Comparative Evaluation

The DHRAM method is applied based on two different kinds of daily flow data: (1) the USGS daily recorded flows are firstly used in dividing into the un-impacted and impacted periods, and (2) naturalized and regulated flows, computed by the daily WRAP model, are used. Both results should be different due to the two reasons: (1) it is impossible to find the exact moment that divide into the un-impacted and impacted periods, and (2) the WRAP model also ideally simulated under the full authorized water use scenarios. In addition, the total of impact points based the WRAP simulation flows is theoretically higher than the USGS recorded flows due to the full water use scenarios if groundwater impacts are excluded.

Both the results may have similarities on the impact points at the five parameter groups, if the simulation is properly performed based on appropriate input datasets and water use scenarios. Thus, if these similarities between both results are proved though comparative analysis at the same point in this research, the daily WRAP model can be applied to predict and quantify the alteration of river flow regimes due to human influences.

Table 8.23 DHRAM results at Control Point CP01 (Naturalized vs. Regulated Flows)

| Control Point: | CP01 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated01 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 157.6 | 0.8912 | 147.1 | 0.93 | | 6.7% | 4.4% |
| February | 189.1 | 0.9158 | 177.1 | 0.9555 | | 6.3% | 4.3% |
| March | 184.1 | 0.836 | 171 | 0.8817 | | 7.1% | 5.5% |
| April | 203.7 | 1.121 | 188.1 | 1.192 | | 7.7% | 6.3% |
| May | 254.2 | 1.009 | 236.1 | 1.056 | | 7.1% | 4.7% |
| June | 295.7 | 1.72 | 274.8 | 1.824 | | 7.1% | 6.0% |
| July | 187.2 | 1.782 | 168.4 | 1.92 | | 10.0% | 7.7% |
| August | 187.8 | 3.015 | 172.5 | 3.241 | | 8.1% | 7.5% |
| September | 212.9 | 1.601 | 191.8 | 1.735 | | 9.9% | 8.4% |
| October | 268 | 1.327 | 251.3 | 1.388 | | 6.2% | 4.6% |
| November | 185.7 | 1.389 | 174.2 | 1.461 | | 6.2% | 5.2% |
| December | 169.9 | 1.11 | 160 | 1.153 | | 5.8% | 3.9% |
| | | | | | Average | 7.4% | 5.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0.5 | 1.955 | 0.13 | 3.96 | | 73.7% | 102.7% |
| 3-day minimum | 0.6246 | 1.885 | 0.19 | 3.43 | | 69.6% | 82.0% |
| 7-day minimum | 1.18 | 1.813 | 0.58 | 2.41 | | 50.9% | 33.0% |
| 30-day minimum | 13.06 | 1.43 | 10.27 | 1.47 | | 21.4% | 2.7% |
| 90-day minimum | 62.3 | 0.8049 | 53.38 | 0.84 | | 14.3% | 4.0% |
| 1-day maximum | 6544 | 1.743 | 6416 | 1.77 | | 2.0% | 1.8% |
| 3-day maximum | 3550 | 1.501 | 3465 | 1.53 | | 2.4% | 2.2% |
| 7-day maximum | 2102 | 1.266 | 2045 | 1.30 | | 2.7% | 2.6% |
| 30-day maximum | 836.8 | 0.9856 | 806 | 1.02 | | 3.7% | 3.2% |
| 90-day maximum | 454.3 | 0.843 | 431 | 0.88 | | 5.1% | 3.8% |
| | | | | | Average | 24.6% | 23.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 163.3 | 0.2483 | 131.6 | 0.2261 | | 19.4% | 8.9% |
| Date of maximum | 191.8 | 0.2314 | 185.3 | 0.2383 | | 3.4% | 3.0% |
| | | | | | Average | 11.4% | 6.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.075 | 0.4586 | 7.475 | 0.4187 | | 5.7% | 8.7% |
| Low pulse duration | 12.75 | 0.4767 | 11.93 | 0.4308 | | 6.4% | 9.6% |
| High pulse count | 2.238 | 0.7048 | 2.225 | 0.7257 | | 0.6% | 3.0% |
| High pulse duration | 3.501 | 0.8156 | 3.485 | 0.8891 | | 0.5% | 9.0% |
| | | | | | Average | 3.3% | 7.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 156.7 | 1.087 | 136.8 | 1.086 | | 12.7% | 0.1% |
| Fall rate | -52.06 | -1.003 | -53.69 | -1.02 | | 3.1% | 1.7% |
| Number of reversals | 61.38 | 0.1761 | 74.2 | 0.174 | | 20.9% | 1.2% |
| | | | | | Average | 12.2% | 1.0% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

Table 8.24 DHRAM results at Control Point CP02 (Naturalized vs. Regulated Flows)

| Control Point: | CP02 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated01 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 301 | 1.141 | 291.2 | 1.166 | | 3.3% | 2.2% |
| February | 341.7 | 1.084 | 330.7 | 1.109 | | 3.2% | 2.3% |
| March | 334 | 0.9794 | 322.1 | 1.006 | | 3.6% | 2.7% |
| April | 357.5 | 1.129 | 343.4 | 1.161 | | 3.9% | 2.8% |
| May | 449.1 | 0.9971 | 432.4 | 1.018 | | 3.7% | 2.1% |
| June | 549.8 | 1.747 | 530.2 | 1.797 | | 3.6% | 2.9% |
| July | 308 | 1.62 | 290.5 | 1.682 | | 5.7% | 3.8% |
| August | 253.1 | 2.392 | 239.4 | 2.498 | | 5.4% | 4.4% |
| September | 333.5 | 1.59 | 314.8 | 1.659 | | 5.6% | 4.3% |
| October | 427.4 | 1.134 | 412.3 | 1.158 | | 3.5% | 2.1% |
| November | 329.3 | 1.439 | 319.1 | 1.476 | | 3.1% | 2.6% |
| December | 308.7 | 1.143 | 299.7 | 1.165 | | 2.9% | 1.9% |
| | | | | | Average | 4.0% | 2.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.209 | 2.178 | 1.72 | 2.49 | | 22.0% | 14.2% |
| 3-day minimum | 2.817 | 2.008 | 2.27 | 2.26 | | 19.6% | 12.5% |
| 7-day minimum | 4.691 | 2.033 | 4.01 | 2.20 | | 14.6% | 8.0% |
| 30-day minimum | 30.61 | 1.118 | 27.38 | 1.15 | | 10.6% | 2.8% |
| 90-day minimum | 98.25 | 0.8236 | 90.41 | 0.84 | | 8.0% | 2.1% |
| 1-day maximum | 7820 | 1.394 | 7740 | 1.40 | | 1.0% | 0.7% |
| 3-day maximum | 4733 | 1.194 | 4669 | 1.21 | | 1.4% | 0.9% |
| 7-day maximum | 3090 | 1.024 | 3040 | 1.04 | | 1.6% | 1.3% |
| 30-day maximum | 1375 | 0.884 | 1347 | 0.90 | | 2.0% | 1.5% |
| 90-day maximum | 779.1 | 0.7937 | 758 | 0.81 | | 2.7% | 1.7% |
| | | | | | Average | 8.3% | 4.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 157.6 | 0.2414 | 151 | 0.2381 | | 4.2% | 1.4% |
| Date of maximum | 187.7 | 0.251 | 186.2 | 0.2553 | | 0.8% | 1.7% |
| | | | | | Average | 2.5% | 1.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 6.463 | 0.5394 | 6.663 | 0.5226 | | 3.1% | 3.1% |
| Low pulse duration | 13.49 | 0.6091 | 13.27 | 0.6599 | | 1.6% | 8.3% |
| High pulse count | 2.675 | 0.7658 | 2.65 | 0.7877 | | 0.9% | 2.9% |
| High pulse duration | 5.356 | 0.6773 | 5.299 | 0.6805 | | 1.1% | 0.5% |
| | | | | | Average | 1.7% | 3.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 190.4 | 0.9338 | 180.8 | 0.9456 | | 5.0% | 1.3% |
| Fall rate | -66.24 | -0.8401 | -66.62 | -0.847 | | 0.6% | 0.8% |
| Number of reversals | 62.45 | 0.143 | 68.5 | 0.1525 | | 9.7% | 6.6% |
| | | | | | Average | 5.1% | 2.9% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 0 |
| Classification | | 1 |
| note: | Un-impacted condition | |

Table 8.25 DHRAM results at Control Point CP08 (Naturalized vs. Regulated Flows)

| Control Point: | CP08 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated01 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 125.3 | 1.414 | 124.4 | 1.417 | | 0.7% | 0.2% |
| February | 150.7 | 1.179 | 149.8 | 1.183 | | 0.6% | 0.3% |
| March | 147.1 | 1.043 | 146.1 | 1.046 | | 0.7% | 0.3% |
| April | 154.4 | 1.179 | 152.9 | 1.181 | | 1.0% | 0.2% |
| May | 196.4 | 1.05 | 194.5 | 1.054 | | 1.0% | 0.4% |
| June | 224.4 | 1.418 | 222.3 | 1.426 | | 0.9% | 0.6% |
| July | 116.1 | 1.735 | 114.8 | 1.744 | | 1.1% | 0.5% |
| August | 61.9 | 1.279 | 60.88 | 1.287 | | 1.6% | 0.6% |
| September | 112 | 1.629 | 110.2 | 1.642 | | 1.6% | 0.8% |
| October | 150.4 | 1.393 | 148.7 | 1.398 | | 1.1% | 0.4% |
| November | 141.1 | 1.47 | 139.7 | 1.479 | | 1.0% | 0.6% |
| December | 122.4 | 1.441 | 121.4 | 1.443 | | 0.8% | 0.1% |
| | | | | | Average | 1.0% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.708 | 1.002 | 2.46 | 1.01 | | 9.3% | 1.2% |
| 3-day minimum | 3.015 | 0.974 | 2.86 | 0.96 | | 5.2% | 1.0% |
| 7-day minimum | 3.816 | 1.03 | 3.64 | 0.98 | | 4.6% | 4.8% |
| 30-day minimum | 12.56 | 0.8365 | 12.26 | 0.84 | | 2.4% | 0.3% |
| 90-day minimum | 38.24 | 0.7582 | 37.57 | 0.76 | | 1.8% | 0.1% |
| 1-day maximum | 3545 | 1.406 | 3529 | 1.41 | | 0.5% | 0.1% |
| 3-day maximum | 2090 | 1.048 | 2077 | 1.05 | | 0.6% | 0.1% |
| 7-day maximum | 1294 | 0.885 | 1286 | 0.88 | | 0.6% | 0.0% |
| 30-day maximum | 563.9 | 0.7527 | 560 | 0.76 | | 0.7% | 0.4% |
| 90-day maximum | 308.9 | 0.7148 | 306 | 0.72 | | 0.9% | 0.4% |
| | | | | | Average | 2.7% | 0.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 78.81 | 0.2986 | 78.2 | 0.2942 | | 0.8% | 1.5% |
| Date of maximum | 187.7 | 0.2637 | 187.7 | 0.2637 | | 0.0% | 0.0% |
| | | | | | Average | 0.4% | 0.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.5 | 0.5446 | 7.713 | 0.5556 | | 2.8% | 2.0% |
| Low pulse duration | 11.48 | 0.5492 | 11.33 | 0.564 | | 1.3% | 2.7% |
| High pulse count | 2.75 | 0.8069 | 2.763 | 0.811 | | 0.5% | 0.5% |
| High pulse duration | 5.452 | 0.6799 | 5.436 | 0.6956 | | 0.3% | 2.3% |
| | | | | | Average | 1.2% | 1.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 77.11 | 1.014 | 74.77 | 1.015 | | 3.0% | 0.1% |
| Fall rate | -29.96 | -0.8709 | -30.14 | -0.8706 | | 0.6% | 0.0% |
| Number of reversals | 83.13 | 0.1457 | 87.59 | 0.142 | | 5.4% | 2.5% |
| | | | | | Average | 3.0% | 0.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 8.26 DHRAM results at Control Point CP10 (Naturalized vs. Regulated Flows)

| Control Point: | CP10 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated01 | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 371.5 | 1.111 | 364.6 | 1.123 | | 1.9% | 1.1% |
| February | 399 | 0.922 | 392.2 | 0.93 | | 1.7% | 0.9% |
| March | 339.4 | 0.7574 | 331.9 | 0.7639 | | 2.2% | 0.9% |
| April | 410.3 | 0.9457 | 400.8 | 0.9536 | | 2.3% | 0.8% |
| May | 498.4 | 0.9128 | 486.7 | 0.922 | | 2.3% | 1.0% |
| June | 536.5 | 1.296 | 522.3 | 1.319 | | 2.6% | 1.8% |
| July | 316.7 | 1.229 | 305.5 | 1.254 | | 3.5% | 2.0% |
| August | 199.2 | 0.6832 | 190.6 | 0.69 | | 4.3% | 1.0% |
| September | 299.6 | 0.9683 | 290.7 | 0.9817 | | 3.0% | 1.4% |
| October | 443.3 | 1.387 | 434.5 | 1.404 | | 2.0% | 1.2% |
| November | 419.9 | 1.279 | 412.8 | 1.293 | | 1.7% | 1.1% |
| December | 358.2 | 0.9849 | 351.8 | 0.9904 | | 1.8% | 0.6% |
| | | | | | Average | 2.4% | 1.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 1.696 | 2.088 | 0.88 | 3.14 | | 48.0% | 50.4% |
| 3-day minimum | 2.135 | 2.004 | 1.32 | 2.70 | | 38.3% | 34.5% |
| 7-day minimum | 3.689 | 1.877 | 2.73 | 2.31 | | 25.9% | 23.3% |
| 30-day minimum | 32.75 | 0.9026 | 31.12 | 0.92 | | 5.0% | 1.5% |
| 90-day minimum | 129.5 | 0.5554 | 124.90 | 0.56 | | 3.6% | 1.0% |
| 1-day maximum | 7061 | 1.104 | 6990 | 1.11 | | 1.0% | 0.7% |
| 3-day maximum | 4707 | 0.8669 | 4644 | 0.87 | | 1.3% | 0.8% |
| 7-day maximum | 3181 | 0.7928 | 3141 | 0.80 | | 1.3% | 0.8% |
| 30-day maximum | 1360 | 0.7428 | 1339 | 0.75 | | 1.5% | 1.0% |
| 90-day maximum | 776.3 | 0.6635 | 762 | 0.67 | | 1.9% | 1.0% |
| | | | | | Average | 12.8% | 11.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 166.4 | 0.2556 | 113.3 | 0.2631 | | 31.9% | 2.9% |
| Date of maximum | 181.2 | 0.2372 | 179.1 | 0.2353 | | 1.2% | 0.8% |
| | | | | | Average | 16.5% | 1.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 9.113 | 0.4966 | 9 | 0.4576 | | 1.2% | 7.9% |
| Low pulse duration | 9.845 | 0.331 | 9.931 | 0.3444 | | 0.9% | 4.0% |
| High pulse count | 4.913 | 0.6631 | 4.925 | 0.6619 | | 0.2% | 0.2% |
| High pulse duration | 3.909 | 0.4972 | 3.841 | 0.5278 | | 1.7% | 6.2% |
| | | | | | Average | 1.0% | 4.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.1 | 0.6384 | 309.9 | 0.6435 | | 6.1% | 0.8% |
| Fall rate | -79.4 | -0.5742 | -79.25 | -0.5875 | | 0.2% | 2.3% |
| Number of reversals | 66.4 | 0.1356 | 72.69 | 0.119 | | 9.5% | 12.2% |
| | | | | | Average | 5.3% | 5.1% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

Table 8.27 DHRAM results at Control Point CP15 (Naturalized vs. Regulated Flows)

Control Point: CP15 Period: 1934-2013

| IHA statistics group | Naturalized | | Regulated01 | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1599 | 1.104 | 1455 | 1.064 | | 9.0% | 3.6% |
| February | 1703 | 1.001 | 1582 | 0.9751 | | 7.1% | 2.6% |
| March | 1445 | 0.7707 | 1292 | 0.817 | | 10.6% | 6.0% |
| April | 1742 | 1.006 | 1523 | 0.9749 | | 12.6% | 3.1% |
| May | 2516 | 1.059 | 2171 | 1.116 | | 13.7% | 5.4% |
| June | 2544 | 1.428 | 2283 | 1.362 | | 10.3% | 4.6% |
| July | 1575 | 1.616 | 1513 | 1.588 | | 3.9% | 1.7% |
| August | 855 | 1.033 | 761.2 | 1.066 | | 11.0% | 3.2% |
| September | 1585 | 1.216 | 1327 | 1.244 | | 16.3% | 2.3% |
| October | 2124 | 1.417 | 1939 | 1.379 | | 8.7% | 2.7% |
| November | 1989 | 1.305 | 1889 | 1.245 | | 5.0% | 4.6% |
| December | 1565 | 1.067 | 1560 | 0.9242 | | 0.3% | 13.4% |
| | | | | | Average | 9.0% | 4.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 59.18 | 1.461 | 44.16 | 0.94 | | 25.4% | 35.5% |
| 3-day minimum | 67.62 | 1.421 | 54.17 | 1.16 | | 19.9% | 18.5% |
| 7-day minimum | 86 | 1.378 | 73.07 | 1.37 | | 15.0% | 0.5% |
| 30-day minimum | 238.1 | 0.9643 | 257.30 | 0.94 | | 8.1% | 2.2% |
| 90-day minimum | 535.8 | 0.6979 | 541.20 | 0.60 | | 1.0% | 13.5% |
| 1-day maximum | 15310 | 0.8621 | 12750 | 0.90 | | 16.7% | 4.5% |
| 3-day maximum | 14200 | 0.8593 | 11900 | 0.91 | | 16.2% | 5.7% |
| 7-day maximum | 12460 | 0.8599 | 10410 | 0.92 | | 16.5% | 7.1% |
| 30-day maximum | 6431 | 0.8038 | 5645 | 0.84 | | 12.2% | 4.6% |
| 90-day maximum | 3657 | 0.7115 | 3297 | 0.76 | | 9.8% | 7.2% |
| | | | | | Average | 14.1% | 9.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 197.3 | 0.2327 | 193 | 0.2518 | | 2.2% | 8.2% |
| Date of maximum | 187.8 | 0.2567 | 177.6 | 0.2739 | | 5.4% | 6.7% |
| | | | | | Average | 3.8% | 7.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.025 | 0.6041 | 6.663 | 0.4074 | | 32.6% | 32.6% |
| Low pulse duration | 20.01 | 1.01 | 13.89 | 0.9515 | | 30.6% | 5.8% |
| High pulse count | 2.75 | 0.7923 | 3.725 | 0.9061 | | 35.5% | 14.4% |
| High pulse duration | 9.291 | 0.5614 | 8.485 | 0.8978 | | 8.7% | 59.9% |
| | | | | | Average | 26.8% | 28.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 373.8 | 0.6418 | 304.7 | 0.632 | | 18.5% | 1.5% |
| Fall rate | -168.3 | -0.6072 | -193.3 | -0.646 | | 14.9% | 6.4% |
| Number of reversals | 53.58 | 0.1281 | 75.9 | 0.2099 | | 41.7% | 63.9% |
| | | | | | Average | 25.0% | 23.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 8.28 DHRAM results at Control Point CP35 (Naturalized vs. Regulated Flows)

| Control Point: | CP35 | Period: | 1934-2013 | | | |
|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated01 | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | |
| January | 94.84 | 2.25 | 93.96 | 2.269 | 0.9% | 0.8% |
| February | 96.71 | 1.479 | 95.43 | 1.495 | 1.3% | 1.1% |
| March | 65.14 | 1.775 | 63.04 | 1.828 | 3.2% | 3.0% |
| April | 141 | 1.841 | 138.1 | 1.873 | 2.1% | 1.7% |
| May | 204.2 | 1.613 | 200.6 | 1.636 | 1.8% | 1.4% |
| June | 211.8 | 1.976 | 207.8 | 2.008 | 1.9% | 1.6% |
| July | 135 | 2.715 | 132.4 | 2.759 | 1.9% | 1.6% |
| August | 60.42 | 2.136 | 58.49 | 2.19 | 3.2% | 2.5% |
| September | 159.5 | 1.97 | 157.2 | 1.995 | 1.4% | 1.3% |
| October | 163.8 | 1.942 | 162.2 | 1.958 | 1.0% | 0.8% |
| November | 113.6 | 1.855 | 112.4 | 1.873 | 1.1% | 1.0% |
| December | 94.16 | 2.414 | 93.29 | 2.434 | 0.9% | 0.8% |
| | | | | Average | 1.7% | 1.5% |
| | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | |
| 1-day minimum | 2.164 | 1.2 | 1.30 | 1.84 | 40.0% | 53.2% |
| 3-day minimum | 2.337 | 1.153 | 1.56 | 1.60 | 33.4% | 38.6% |
| 7-day minimum | 2.828 | 1.081 | 2.15 | 1.31 | 24.0% | 21.1% |
| 30-day minimum | 7.356 | 0.8235 | 6.72 | 0.86 | 8.6% | 4.1% |
| 90-day minimum | 20.65 | 0.6713 | 19.49 | 0.68 | 5.6% | 0.8% |
| 1-day maximum | 2775 | 1.109 | 2769 | 1.11 | 0.2% | 0.2% |
| 3-day maximum | 2293 | 1.045 | 2287 | 1.05 | 0.3% | 0.2% |
| 7-day maximum | 1659 | 1.01 | 1653 | 1.01 | 0.4% | 0.3% |
| 30-day maximum | 690.2 | 0.9501 | 686 | 0.96 | 0.6% | 0.5% |
| 90-day maximum | 321.9 | 0.8916 | 319 | 0.90 | 1.0% | 0.7% |
| | | | | Average | 11.4% | 12.0% |
| | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | |
| Date of minimum | 180.6 | 0.2573 | 174 | 0.2492 | 3.7% | 3.1% |
| Date of maximum | 198.4 | 0.2498 | 200.2 | 0.253 | 0.9% | 1.3% |
| | | | | Average | 2.3% | 2.2% |
| | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | |
| Low pulse count | 7.213 | 0.5371 | 7.75 | 0.5244 | 7.4% | 2.4% |
| Low pulse duration | 12.74 | 0.69 | 12.32 | 0.6372 | 3.3% | 7.7% |
| High pulse count | 2.925 | 0.8511 | 2.925 | 0.8511 | 0.0% | 0.0% |
| High pulse duration | 5.651 | 0.6739 | 5.641 | 0.6764 | 0.2% | 0.4% |
| | | | | Average | 2.7% | 2.6% |
| | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | |
| Rise rate | 99.08 | 0.9965 | 95.94 | 1.012 | 3.2% | 1.6% |
| Fall rate | -25.62 | -0.8949 | -25.82 | -0.8924 | 0.8% | 0.3% |
| Number of reversals | 63.75 | 0.1421 | 67.9 | 0.1419 | 6.5% | 0.1% |
| | | | | Average | 3.5% | 0.7% |
| | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 8.29 allows easy comparison of both analysis results at the four control points in the Sabine River Basin. This table indicates that both the results have considerable similarities.

Table 8.29 A Total of Impact Points on DHRAM Analyses
in the Sabine River Basin

| Control Point | Total of Impact Points | |
|---|---|---|
| | USGS Recorded Flow (Un-impacted vs. Impacted) | WRAP Simulation Flow (Naturalized vs. Regulated) |
| BSBS | 3 | 0 |
| SRGW | 5 | 9 |
| SRBE | 3 | 10 |
| SRRL | 6 | 11 |

Table 8.30 presents both the analysis results at the four control points in the Neches River Basin. This indicates that both results have similar hydrologic alteration characteristic at the four control points expect for NERO. At the control point NERO, both the results have the same impact points on the four parameter groups except for the flow timing parameter group.

Table 8.30 A Total of Impact Points on DHRAM Analyses
in the Neches River Basin

| Control Point | Total of Impact Points | |
|---|---|---|
| | USGS Recorded Flow (Un-impacted vs. Impacted) | WRAP Simulation Flow (Naturalized vs. Regulated) |
| NENE | 8 | 6 |
| NERO | 0 | 5 |
| NEEV | 10 | 11 |
| VIKO | 4 | 0 |

Both the comparisons prove that the regulated flows, computed in the simulation of the daily WRAP model can relatively represent a specific condition of water resources development, regulation and use in the Sabine and Neches River Basins.

Table 8.31 provides both the analysis results at the six control points in the GSA River Basin.  The totals of impact points of the USGS recorded flows are totally higher than the WRAP simulation flows. Even though the differences between both the impact points at the control point CP 10 and CP15 are ignorable, both the results are completely different from each other, If both the results of analyses are closely reviewed, the alterations of flow timings on both the results have similar tendency while the alteration of flow amount have totally different tendency.

Table 8.31 A Total of Impact Points on DHRAM Analyses in the GSA River Basins

| Control Point | Total of Impact Points | |
|---|---|---|
| | USGS Recorded Flow (Un-impacted vs. Impacted) | WRAP Simulation Flow (Naturalized vs. Regulated) |
| CP01 | 9 | 1 |
| CP02 | 7 | 0 |
| CP08 | 6 | 0 |
| CP10 | 2 | 1 |
| CP15 | 1 | 0 |
| CP35 | 7 | 0 |

The average monthly flows and minimum and maximum flows for the impacted periods are considerably greater than un-impacted periods in the USGS recorded flows while there are no evident long-term trends in precipitation in Texas, including the GSA River Basins (Wurbs and Zhang, 2014). These are presumably attributed to return flows from municipal ground water use within the watershed (Wurbs and Zhang, 2014). Although the regulated flows cannot represent the USGS recorded data due to the return flows, the alterations of flow regimes between naturalized and regulated flows can represent the alterations of flow regimes on the GSA River flows by other human influences.

# CHAPTER IX

# EVALUATING IMPACTS OF THE ENVIRONMENTAL FLOW STANDARDS

The effects of the SB3 environmental flow standards in the Sabine, Neches, and GSA River Basins are evaluated in this chapter based on comparative frequency analyses of WAM naturalized, regulated, and unappropriated flows.

## 9.1 Impacts on Future Water Rights

SB3 environmental flow standards (EFS) conceptually do not impact existing water rights because the EFS have junior priorities relative to all existing water rights. The environmental flow standards were established to secure the current flow regimes from future water rights. The EFS at a site may influence future water rights up and downstream of sites. However, the flows protected by a EFS at a site can be depleted for water rights at downstream sites.

The daily WRAP model computes sequences of regulated and unappropriated flows based on naturalized flow datasets for the period-of-analysis. Unappropriated flows are naturalized flows still remaining after the streamflow depletions are made and return flows are returned for all the water rights (Wurbs, 2013b). In other words, future water rights can appropriate the unappropriated flows. Therefore, the impacts on future water rights by the EFS can be evaluated through the comparison of unappropriated flows at a control point with and without the EFS using the daily WRAP model.

### 9.1.1 Sabine River Basin

The Sabine WAM has 18 primary control points. SB3 EFSs were incorporated at five of these control points which are listed in Table 6.2. Table 9.1 presents the unappropriated flow frequency metrics with and without EFS at the control points CFGV, SRWP, and SRMN. There is no EFS influence on the unappropriated flows at the control point CFGV.

The unappropriated flows with EFS slightly decrease than the flows without EFS at the control points SRWP and SRMN.

Table 9.1 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CFGV, SRWP, and SRMN in the Sabine River Basin

| | CFGV | | SRWP | | SRMN | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 17.8 | 17.3 | 170.0 | 168.0 | 510.8 | 487.5 |
| Stan Dev | 169.3 | 164.6 | 1,156 | 1,151 | 1,894 | 1,876 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20% | 0.0 | 0.0 | 0.0 | 0.0 | 148.9 | 43.6 |
| 15% | 0.0 | 0.0 | 0.0 | 0.0 | 568.9 | 433.1 |
| 10% | 0.0 | 0.0 | 0.1 | 0.0 | 1,295 | 1,169 |
| 5% | 5.2 | 4.2 | 253.7 | 213.4 | 2,945 | 2,886 |
| 2% | 168.0 | 162.8 | 2,635 | 2,600 | 5,997 | 5,867 |
| 1% | 481.5 | 468.0 | 5,055 | 5,042 | 9,096 | 9,031 |
| 0.50% | 994.7 | 975.1 | 7,944 | 7,904 | 13,030 | 12,980 |
| Maximum | 8,577 | 8,577 | 35,453 | 35,453 | 34,590 | 34,590 |

Table 9.2 provides unappropriated flow frequency metrics with and without EFS at the control points LFQT, BSBS, and SRGW. SB3 EFS was incorporated into the control points BSBS and SRGW. The unappropriated flows with EFS are smaller than the flows without EFS at the three control points. EFS significantly impacts the unappropriated flows at the control point BSBS, but the influence of EFS is much less at the control point LFQT.

Table 9.2 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points LFQT, BSBS, and SRGW in the Sabine River Basin

| | LFQT | | BSBS | | SRGW | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 68.8 | 65.7 | 130.8 | 97.2 | 1,423 | 1,202 |
| Stan Dev | 452.4 | 449.1 | 380.4 | 304.2 | 3,971 | 3,670 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25% | 0.0 | 0.0 | 16.9 | 0.0 | 577.4 | 87.0 |
| 20% | 5.4 | 0.0 | 132.5 | 50.6 | 1,664 | 879.0 |
| 15% | 44.7 | 32.5 | 262.6 | 156.7 | 2,989 | 2,114 |
| 10% | 124.3 | 112.3 | 433.4 | 320.0 | 4,816 | 4,029 |
| 5% | 298.9 | 285.9 | 770.2 | 611.0 | 8,153 | 7,307 |
| 2% | 668.1 | 655.9 | 1,319 | 1,048 | 13,335 | 12,402 |
| 1% | 1,152 | 1,120 | 1,757 | 1,402 | 18,089 | 16,961 |
| 0.50% | 2,063 | 1,999 | 2,272 | 1,836 | 23,784 | 22,251 |
| Maximum | 22,647 | 22,647 | 7,902 | 6,317 | 84,596 | 84,596 |

Table 9.3 tabulates unappropriated flow frequency metrics with and without EFS at the control points SRBE, MCTT, and MBGR. SB3 EFS was incorporated into the control point SRBE. The unappropriated flows with EFS are smaller than the flows without EFS at the three control points. EFS significantly impacts the unappropriated flows at control point SRBE, but the influence of the EFS is minimal at control points MCTT and MBGR.

Table 9.3 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points SRBE, MCTT, and MBGR in the Sabine River Basin

| | SRBE | | MCTT | | MBGR | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 2,160 | 1,834 | 94.1 | 93.6 | 105.1 | 104.4 |
| Stan Dev | 5,317 | 4,974 | 373.1 | 372.7 | 543.1 | 542.5 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25% | 1,318 | 250.0 | 0.0 | 0.0 | 1.0 | 0.8 |
| 20% | 2,997 | 1,773 | 5.2 | 4.3 | 4.2 | 3.8 |
| 15% | 5,053 | 3,792 | 89.8 | 87.6 | 18.8 | 17.1 |
| 10% | 7,919 | 6,769 | 240.3 | 238.0 | 118.6 | 115.9 |
| 5% | 12,685 | 11,435 | 533.3 | 530.3 | 548.4 | 543.0 |
| 2% | 18,677 | 17,528 | 1,138 | 1,138 | 1,502 | 1,497 |
| 1% | 23,300 | 22,490 | 1,758 | 1,758 | 2,451 | 2,443 |
| 0.50% | 28,847 | 27,701 | 2,509 | 2,509 | 3,575 | 3,575 |
| Maximum | 99,116 | 99,440 | 10,250 | 10,250 | 22,270 | 22,270 |

Table 9.4 tabulates the unappropriated flow frequency metrics with and without EFS at the control points SRLP, TCSV, and BTTR. The unappropriated flows with EFS are smaller than the flows without EFS at the three control points. The influences by EFS are imperceptible at the control point SRLP, however, EFS considerably reduces the unappropriated flows at the control points TCSV and BTTR.

Table 9.4 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points SRLP, TCSV, and BTTR in the Sabine River Basin

| | SRLP | | TCSV | | BTTR | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 3,033 | 3,001 | 101.7 | 101.2 | 293.8 | 284.2 |
| Stan Dev | 7,178 | 7,172 | 370.3 | 370.1 | 969.1 | 962.5 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 | 0.5 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 5.9 | 3.3 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 14.6 | 11.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 30.5 | 26.2 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 59.6 | 53.1 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 114.9 | 105.9 |
| 25% | 1,752 | 1,424 | 10.0 | 7.8 | 165.5 | 152.8 |
| 20% | 4,439 | 4,302 | 49.9 | 47.8 | 251.0 | 234.4 |
| 15% | 7,458 | 7,416 | 113.5 | 112.0 | 397.7 | 374.2 |
| 10% | 11,534 | 11,486 | 238.9 | 236.6 | 685.7 | 655.8 |
| 5% | 18,044 | 18,040 | 589.2 | 587.2 | 1,455 | 1,411 |
| 2% | 25,981 | 25,973 | 1,257 | 1,254 | 2,925 | 2,854 |
| 1% | 31,457 | 31,370 | 1,865 | 1,865 | 4,152 | 4,091 |
| 0.50% | 38,707 | 38,707 | 2,477 | 2,477 | 5,825 | 5,807 |
| Maximum | 99,440 | 99,440 | 11,230 | 11,230 | 28,820 | 28,820 |

Table 9.5 provides the unappropriated flow frequency metrics with and without EFS at the control points SRBU, BARP, and SRBW. The unappropriated flows are decreased by EFS at the three control points, but the influences of the EFS are relatively small at all the control points.

Table 9.5 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points SRBU, BARP, and SRBW in the Sabine River Basin

| | SRBU | | BARP | | SRBW | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 5,525 | 5,474 | 936.3 | 901.7 | 7,276 | 7,177 |
| Stan Dev | 12,451 | 12,449 | 2,584 | 2,572 | 13,896 | 13,930 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 5.3 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 45.7 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 76.7 | 45.8 | 182.5 | 32.4 |
| 60% | 3.0 | 0.0 | 142.8 | 116.1 | 678.8 | 462.4 |
| 50% | 117.6 | 85.3 | 242.1 | 207.9 | 1,321 | 1,103 |
| 40% | 360.5 | 317.0 | 395.6 | 361.2 | 2,365 | 2,193 |
| 30% | 1,247 | 1,127 | 633.5 | 591.3 | 4,778 | 4,525 |
| 25% | 3,210 | 2,872 | 826.9 | 778.1 | 7,170 | 7,093 |
| 20% | 7,572 | 7,370 | 1,106 | 1,054 | 10,938 | 10,890 |
| 15% | 13,329 | 13,286 | 1,548 | 1,494 | 16,611 | 16,612 |
| 10% | 20,901 | 20,856 | 2,330 | 2,267 | 24,331 | 24,315 |
| 5% | 31,924 | 31,872 | 4,084 | 3,988 | 36,214 | 36,214 |
| 2% | 45,656 | 45,607 | 7,004 | 6,939 | 51,543 | 51,543 |
| 1% | 58,435 | 58,435 | 9,853 | 9,834 | 63,867 | 63,867 |
| 0.50% | 71,695 | 71,695 | 14,240 | 14,193 | 78,537 | 78,537 |
| Maximum | 148,363 | 148,363 | 104,595 | 104,595 | 187,197 | 187,197 |

Table 9.6 presents unappropriated flow frequency metrics with and without EFS at the control points SRRL, CBMV, and SRSL. SB3 EFS was incorporated into the control point SRBE. The unappropriated flows with EFS tremendously decrease than the flows at control point SRRL. However, there are no differences between the flows with and without EFS at the control points CBMV and SRSL.

Table 9.6 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points SRRL, CBMV, and SRSL in the Sabine River Basin

| | SRRL | | CBMV | | SRSL | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 7,609 | 5,223 | 227.7 | 227.8 | 5,693 | 5,694 |
| Stan Dev | 12,606 | 8,954 | 566.2 | 566.2 | 9,030 | 9,031 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 65.5 | 65.0 |
| 85% | 0.0 | 0.0 | 0.1 | 0.1 | 172.3 | 172.7 |
| 80% | 143.7 | 28.7 | 1.0 | 1.0 | 319.0 | 318.7 |
| 75% | 412.3 | 157.7 | 3.2 | 3.2 | 487.4 | 487.3 |
| 70% | 708.7 | 307.0 | 6.7 | 6.7 | 674.4 | 673.4 |
| 60% | 1,431 | 672.8 | 17.7 | 17.7 | 1,197 | 1,198 |
| 50% | 2,435 | 1,314 | 37.7 | 37.7 | 1,955 | 1,955 |
| 40% | 4,008 | 2,474 | 72.8 | 72.9 | 3,191 | 3,190 |
| 30% | 6,881 | 4,698 | 140.4 | 140.5 | 5,397 | 5,396 |
| 25% | 9,019 | 6,344 | 194.4 | 194.6 | 7,020 | 7,028 |
| 20% | 12,315 | 8,715 | 274.3 | 274.4 | 9,314 | 9,321 |
| 15% | 16,959 | 12,089 | 403.0 | 403.5 | 12,634 | 12,638 |
| 10% | 22,710 | 16,030 | 620.7 | 622.4 | 16,554 | 16,560 |
| 5% | 32,461 | 22,797 | 1,104 | 1,104 | 23,366 | 23,366 |
| 2% | 46,611 | 32,831 | 1,848 | 1,848 | 33,402 | 33,443 |
| 1% | 57,958 | 40,645 | 2,515 | 2,515 | 41,169 | 41,133 |
| 0.50% | 69,353 | 48,823 | 3,459 | 3,459 | 49,610 | 49,610 |
| Maximum | 215,512 | 164,417 | 16,098 | 16,098 | 164,417 | 164,417 |

9.1.2 Neches River Basin

The Neches WAM has 20 primary control points. SB3 EFSs were incorporated into the five control points, listed in Table 6.3. Table 9.7 presents the unappropriated flow frequency metrics with and without EFS at the control points KIBR, NEPA, and NENE. SB3 EFS was incorporated into the control point NENE. The unappropriated flows with EFS decrease than the flows without EFS at the three control points. The EFS tremendously decrease the flows at the control point NENE.

Table 9.7 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points KIBR, NEPA, and NENE in the Neches River Basin

| | KIBR | | NEPA | | NENE | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 69.3 | 67.6 | 204.7 | 198.2 | 536.0 | 385.0 |
| Stan Dev | 439.9 | 434.7 | 1,053 | 1,033 | 1,678 | 1,391 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 99.7 | 0.0 |
| 25% | 0.0 | 0.0 | 0.0 | 0.0 | 278.3 | 60.5 |
| 20% | 0.0 | 0.0 | 0.0 | 0.0 | 495.1 | 174.8 |
| 15% | 0.0 | 0.0 | 0.0 | 0.0 | 817.3 | 389.0 |
| 10% | 0.0 | 0.0 | 0.0 | 0.0 | 1,434 | 893.8 |
| 5% | 160.9 | 133.3 | 1,094 | 991.8 | 3,037 | 2,355 |
| 2% | 1,127 | 1,116 | 3,586 | 3,511 | 5,832 | 4,782 |
| 1% | 2,160 | 2,092 | 5,625 | 5,509 | 8,267 | 7,034 |
| 0.50% | 3,074 | 3,055 | 7,449 | 7,386 | 10,654 | 8,858 |
| Maximum | 12,163 | 12,163 | 24,563 | 24,563 | 46,537 | 40,548 |

Table 9.8 provides the unappropriated flow frequency metrics with and without EFS at the control points NEAL, NEDI, and NERO. SB3 EFS was incorporated into the control point NERO. The unappropriated flows with EFS are smaller than the flows without EFS at the three control points. The EFS considerably decreases flows at the control point NERO.

Table 9.8 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points NEAL, NEDI, and NERO in the Neches River Basin

| | NEAL | | NEDI | | NERO | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 1,207 | 1,135 | 2,241 | 2,072 | 3,451 | 2,551 |
| Stan Dev | 2,695 | 2,676 | 4,363 | 4,325 | 6,667 | 5,241 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 140.9 | 0.3 | 760.0 | 247.2 | 1,288 | 122.2 |
| 30% | 840.3 | 598.0 | 1,972 | 1,443 | 3,187 | 1,607 |
| 25% | 1,269 | 1,030 | 2,776 | 2,267 | 4,369 | 2,651 |
| 20% | 1,868 | 1,658 | 3,938 | 3,521 | 5,943 | 4,153 |
| 15% | 2,663 | 2,539 | 5,270 | 4,983 | 7,993 | 6,192 |
| 10% | 3,832 | 3,720 | 7,256 | 7,085 | 10,968 | 9,071 |
| 5% | 6,171 | 6,063 | 10,589 | 10,466 | 16,359 | 13,777 |
| 2% | 9,557 | 9,474 | 15,312 | 15,196 | 23,872 | 19,582 |
| 1% | 12,544 | 12,423 | 19,206 | 19,126 | 30,374 | 24,141 |
| 0.50% | 15,935 | 15,859 | 24,743 | 24,620 | 38,389 | 28,372 |
| Maximum | 49,809 | 49,809 | 94,643 | 94,643 | 99,417 | 60,202 |

Table 9.9 presents the unappropriated flow frequency metrics with and without EFS at the control points MUTY, MUJA, and EFACU. The unappropriated flows with EFS are slightly smaller than the flows without EFS at the three control points.

Table 9.9 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points MUTY, MUJA, and EFACU in the Neches River Basin

| | MUTY | | MUJA | | EFACU | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 18.9 | 18.7 | 125.1 | 122.9 | 157.8 | 149.6 |
| Stan Dev | 128.2 | 128.1 | 562.6 | 561.0 | 453.9 | 445.1 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 27.4 | 6.0 |
| 25% | 0.0 | 0.0 | 0.0 | 0.0 | 71.0 | 50.5 |
| 20% | 0.0 | 0.0 | 0.0 | 0.0 | 139.7 | 116.1 |
| 15% | 0.0 | 0.0 | 0.0 | 0.0 | 255.7 | 228.2 |
| 10% | 0.0 | 0.0 | 54.4 | 12.0 | 466.4 | 436.9 |
| 5% | 44.9 | 43.1 | 805.4 | 790.2 | 950.1 | 928.2 |
| 2% | 260.2 | 258.6 | 1,941 | 1,934 | 1,709 | 1,678 |
| 1% | 532.2 | 532.2 | 3,096 | 3,087 | 2,280 | 2,262 |
| 0.50% | 933.2 | 933.2 | 3,948 | 3,948 | 2,791 | 2,791 |
| Maximum | 3,825 | 3,825 | 10,910 | 10,910 | 12,278 | 12,278 |

Table 9.10 tabulates the unappropriated flow frequency metrics with and without EFS at the control points ANAL, ANLU, and ATCH. SB3 EFS was incorporated into the control point ANAL. The unappropriated flows with EFS are smaller than the flows

without EFS at the three control points. The EFS considerably decrease the flows at control point ANAL.

Table 9.10 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points ANAL, ANLU, and ATCH in the Neches River Basin

| | ANAL | | ANLU | | ATCH | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 963.7 | 808.3 | 1,304 | 1,286 | 586.8 | 580.3 |
| Stan Dev | 2,525 | 2,343 | 3,208 | 3,199 | 1,533 | 1,530 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 153.0 | 4.8 | 339.0 | 240.0 | 116.3 | 83.7 |
| 25% | 587.8 | 265.5 | 993.2 | 912.2 | 347.2 | 327.0 |
| 20% | 1,126 | 680.6 | 1,739 | 1,674 | 692.6 | 670.7 |
| 15% | 1,883 | 1,342 | 2,714 | 2,676 | 1,142 | 1,126 |
| 10% | 3,144 | 2,473 | 4,379 | 4,344 | 1,904 | 1,882 |
| 5% | 5,602 | 4,922 | 7,527 | 7,504 | 3,441 | 3,417 |
| 2% | 9,604 | 8,927 | 12,289 | 12,259 | 5,845 | 5,822 |
| 1% | 12,137 | 11,625 | 15,273 | 15,259 | 7,571 | 7,558 |
| 0.50% | 15,396 | 15,102 | 18,649 | 18,649 | 9,230 | 9,222 |
| Maximum | 38,281 | 34,623 | 55,506 | 55,506 | 41,600 | 41,600 |

Table 9.11 provides the unappropriated flow frequency metrics with and without EFS at the control points AYSA, ANSR, and NETB. The EFS slightly decrease the unappropriated flows at the three control points, but the changes are small.

Table 9.11 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points AYSA, ANSR, and NETB in the Neches River Basin

| | AYSA | | ANSR | | NETB | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 130.3 | 129.2 | 3,050 | 2,915 | 6,159 | 5,742 |
| Stan Dev | 435.6 | 433.3 | 6,372 | 6,142 | 11,509 | 11,246 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 37.2 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 1,515 | 813.5 |
| 30% | 4.7 | 3.9 | 1,635 | 1,251 | 5,002 | 3,384 |
| 25% | 23.3 | 21.5 | 3,089 | 2,744 | 7,584 | 6,299 |
| 20% | 71.8 | 68.7 | 5,062 | 4,835 | 10,616 | 9,906 |
| 15% | 168.2 | 165.1 | 7,387 | 7,202 | 14,725 | 14,275 |
| 10% | 368.9 | 363.7 | 11,045 | 10,866 | 21,755 | 21,268 |
| 5% | 827.8 | 825.0 | 16,947 | 16,626 | 31,673 | 31,073 |
| 2% | 1,421 | 1,416 | 23,967 | 22,929 | 42,617 | 41,699 |
| 1% | 1,954 | 1,931 | 28,445 | 27,370 | 49,683 | 48,079 |
| 0.50% | 2,565 | 2,547 | 32,616 | 31,289 | 57,379 | 54,141 |
| Maximum | 12,637 | 12,637 | 89,980 | 89,980 | 150,680 | 150,680 |

Table 9.12 tabulates the unappropriated flow frequency metrics with and without EFS at the control points NEEV, VIKO, and PISL. SB3 EFS was incorporated into the control points NEEV and VIKO. The unappropriated flows are decreased by the EFS at the two control points NEEV and VIKO. The unappropriated flows with and without EFS are identical at control point PISL.

Table 9.12 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points NEEV, VIKO, and PISL in the Neches River Basin

| | NEEV | | VIKO | | PISL | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 6,710 | 6,037 | 1,544 | 1,194 | 686.8 | 686.8 |
| Stan Dev | 11,574 | 12,001 | 3,222 | 2,811 | 1,574 | 1,574 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 57.7 | 0.0 | 0.0 | 0.0 |
| 50% | 609.2 | 159.6 | 263.9 | 48.9 | 0.0 | 0.0 |
| 40% | 2,336 | 1,145 | 626.9 | 246.6 | 240.8 | 240.8 |
| 30% | 6,327 | 3,343 | 1,200 | 698.2 | 575.0 | 575.0 |
| 25% | 9,063 | 5,877 | 1,635 | 1,050 | 802.8 | 802.8 |
| 20% | 12,269 | 9,308 | 2,241 | 1,575 | 1,090 | 1,090 |
| 15% | 16,643 | 14,048 | 3,120 | 2,323 | 1,515 | 1,515 |
| 10% | 23,825 | 22,441 | 4,547 | 3,626 | 2,072 | 2,072 |
| 5% | 32,753 | 33,718 | 7,537 | 6,522 | 3,186 | 3,186 |
| 2% | 40,316 | 46,286 | 10,946 | 9,951 | 4,817 | 4,817 |
| 1% | 44,770 | 51,908 | 14,668 | 13,119 | 6,439 | 6,439 |
| 0.50% | 53,341 | 56,828 | 19,746 | 17,136 | 7,812 | 7,812 |
| Maximum | 157,127 | 183,372 | 64,700 | 57,550 | 42,449 | 42,449 |

Table 9.13 provides the unappropriated flow frequency metrics with and without EFS at the control points NEBA and NESL. Both the flows at the control points NEBA and NESL are exactly the same..

Table 9.13 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points NEBA and NESL in the Neches River Basin

| | NEBA | | NESL | |
|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 10,406 | 10,406 | 12,213 | 12,213 |
| Stan Dev | 17,381 | 17,381 | 19,416 | 19,416 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.6 | 0.6 |
| 90% | 0.0 | 0.0 | 0.9 | 0.9 |
| 85% | 0.0 | 0.0 | 26.5 | 26.5 |
| 80% | 0.0 | 0.0 | 121.3 | 121.3 |
| 75% | 0.0 | 0.0 | 285.6 | 285.6 |
| 70% | 0.0 | 0.0 | 555.4 | 555.4 |
| 60% | 267.4 | 267.4 | 1,580 | 1,580 |
| 50% | 1,926 | 1,926 | 3,388 | 3,388 |
| 40% | 4,806 | 4,806 | 6,388 | 6,388 |
| 30% | 9,922 | 9,922 | 11,606 | 11,606 |
| 25% | 13,590 | 13,590 | 15,267 | 15,267 |
| 20% | 18,421 | 18,421 | 20,752 | 20,752 |
| 15% | 25,038 | 25,038 | 27,931 | 27,931 |
| 10% | 34,995 | 34,995 | 38,801 | 38,801 |
| 5% | 48,361 | 48,361 | 56,564 | 56,564 |
| 2% | 61,643 | 61,643 | 72,328 | 72,328 |
| 1% | 73,687 | 73,687 | 81,939 | 81,939 |
| 0.50% | 89,131 | 89,131 | 94,265 | 94,265 |
| Maximum | 183,372 | 183,372 | 199,611 | 199,611 |

### 9.1.3 GSA River Basins

The GSA WAM has 46 primary control points. SB3 EFSs were incorporated into fifteen control points that include thirteen primary control points and two secondary control points which are tabulated in Table 6.5. The 15 primary control points selected to compare unappropriated flow frequency metrics with and without EFS include 13 primary control points that have SB3 EFS and two other control points are located at the confluence of the Guadalupe and San Antonio Rivers and the estuary of both rivers.

Table 9.14 presents the unappropriated flow frequency metrics with and without EFS at the control points CP01, CP02, and CP08. The unappropriated flows with EFS are decreased by the EFS at the three control points.

Table 9.14 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CP01, CP02, and CP08 in the GSA River Basins

| | CP01 | | CP02 | | CP08 | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 42.4 | 29.3 | 77.3 | 50.6 | 115.5 | 83.9 |
| Stan Dev | 273.4 | 227.2 | 453.1 | 348.5 | 489.2 | 413.0 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15% | 0.0 | 0.0 | 0.0 | 0.0 | 89.4 | 0.0 |
| 10% | 0.0 | 0.0 | 0.0 | 0.0 | 307.5 | 143.7 |
| 5% | 74.9 | 0.0 | 215.1 | 0.0 | 703.5 | 495.7 |
| 2% | 779.4 | 513.4 | 1,311 | 910.2 | 1,323 | 1,095 |
| 1% | 1,257 | 989.9 | 2,263 | 1,388 | 2,022 | 1,707 |
| 0.50% | 1,625 | 1,302 | 3,134 | 2,174 | 2,833 | 2,427 |
| Maximum | 16,263 | 15,510 | 16,898 | 14,970 | 20,517 | 20,424 |

Table 9.15 provides the unappropriated flow frequency metrics with and without EFS at the control points CP10, CP11, and CP13. The unappropriated flows with EFS are smaller than the flows without EFS at the three control points.

Table 9.15 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CP10, CP11, and CP13 in the GSA River Basins

| | CP10 | | CP11 | | CP13 | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 323.0 | 208.4 | 115.8 | 74.0 | 215.8 | 179.7 |
| Stan Dev | 1,269 | 962.0 | 668.6 | 460.1 | 1,137 | 1,091 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 9.8 | 1.9 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 31.3 | 10.6 |
| 25% | 0.0 | 0.0 | 0.0 | 0.0 | 53.0 | 28.1 |
| 20% | 121.9 | 42.9 | 7.8 | 1.1 | 91.9 | 57.0 |
| 15% | 454.4 | 165.4 | 38.3 | 9.9 | 160.8 | 110.1 |
| 10% | 899.6 | 456.5 | 139.0 | 71.0 | 332.5 | 228.3 |
| 5% | 1,796 | 1,053 | 514.3 | 292.1 | 905.8 | 642.8 |
| 2% | 3,512 | 2,542 | 1,486 | 929.4 | 2,397 | 1,989 |
| 1% | 5,286 | 3,958 | 2,555 | 1,715 | 4,437 | 3,972 |
| 0.50% | 7,854 | 5,892 | 3,948 | 2,960 | 6,896 | 6,438 |
| Maximum | 71,622 | 40,412 | 37,291 | 20,510 | 65,183 | 65,170 |

Table 9.16 presents unappropriated flow frequency metrics with and without EFS at control points CP14, CP15, and CP28. The unappropriated flows with EFS decrease relative to the flows without EFS at the three control points. However, the unappropriated flow regimes with EFS are slightly improved than the flow regimes without EFS at the control points CP14 and CP15.

Table 9.16 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CP14, CP15, and CP28 in the GSA River Basins

| | CP14 | | CP15 | | CP28 | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 2,062 | 1,414 | 2,389 | 1,769 | 124.9 | 80.8 |
| Stan Dev | 5,308 | 4,606 | 5,204 | 4,577 | 829.2 | 710.7 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 47.6 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 100.5 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 95.9 | 154.9 | 0.0 | 0.0 |
| 60% | 0.0 | 29.9 | 706.1 | 316.7 | 0.0 | 0.0 |
| 50% | 241.1 | 121.9 | 1,159 | 570.3 | 0.0 | 0.0 |
| 40% | 725.6 | 252.3 | 1,416 | 757.7 | 0.0 | 0.0 |
| 30% | 1,156 | 383.9 | 1,639 | 955.4 | 0.0 | 0.0 |
| 25% | 1,626 | 511.2 | 2,084 | 1,075 | 0.0 | 0.0 |
| 20% | 2,293 | 714.0 | 2,471 | 1,354 | 0.0 | 0.0 |
| 15% | 3,180 | 1,252 | 3,305 | 1,964 | 6.4 | 0.0 |
| 10% | 5,808 | 3,672 | 6,059 | 4,445 | 204.3 | 0.0 |
| 5% | 10,658 | 8,610 | 10,629 | 9,275 | 554.9 | 280.8 |
| 2% | 17,232 | 14,195 | 16,943 | 14,712 | 1,295 | 942.2 |
| 1% | 23,653 | 20,402 | 23,801 | 21,289 | 2,392 | 1,710 |
| 0.50% | 32,627 | 29,582 | 33,655 | 30,452 | 4,122 | 2,958 |
| Maximum | 102,902 | 88,752 | 92,130 | 81,426 | 44,209 | 41,425 |

Table 9.17 presents the unappropriated flow frequency metrics with and without EFS at the control points CP29, CP32, and CP35. The unappropriated flows with EFS decrease relative to the flows without EFS at the three control points.

Table 9.17 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CP29, CP32, and CP35 in the GSA River Basins

| | CP29 | | CP32 | | CP35 | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 188.6 | 114.6 | 250.8 | 189.0 | 166.3 | 131.9 |
| Stan Dev | 1,144.1 | 811.4 | 1,147 | 1,002 | 685.3 | 564.6 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 98% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 80% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 75% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 70% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 60% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 50% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40% | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |
| 30% | 0.0 | 0.0 | 0.0 | 0.0 | 37.8 | 4.8 |
| 25% | 0.0 | 0.0 | 0.8 | 0.0 | 64.5 | 37.1 |
| 20% | 0.0 | 0.0 | 77.0 | 0.0 | 109.0 | 81.4 |
| 15% | 54.0 | 0.0 | 224.1 | 68.2 | 188.0 | 152.7 |
| 10% | 272.6 | 48.4 | 517.7 | 292.5 | 341.7 | 288.4 |
| 5% | 793.4 | 476.6 | 1,234 | 918.4 | 764.3 | 620.0 |
| 2% | 2,007 | 1,369 | 2,960 | 2,388 | 1,696 | 1,311 |
| 1% | 4,039 | 2,546 | 4,935 | 4,076 | 3,033 | 2,344 |
| 0.50% | 7,144 | 4,293 | 7,211 | 5,991 | 4,789 | 3,815 |
| Maximum | 49,210 | 36,296 | 38,636 | 37,551 | 15,800 | 12,308 |

Table 9.18 presents the unappropriated flow frequency metrics with and without EFS at the control points CP37, CP38, and CPEST. The unappropriated flows with EFS are less than the flows without EFS at the control point CP37 like twelve other control points. Both the unappropriated flows with and without EFS are completely identical at the control points CP38 and CPEST. This attributes that the flows, used for EFS are fully returned to their downstream.

Table 9.18 Unappropriated Flow Frequency Metrics Without and With EFS at the Control Points CP37, CP38, and CPEST in the GSA River Basins

| | CP37 | | CP38 | | CPEST | |
|---|---|---|---|---|---|---|
| | Without EFS | With EFS | Without EFS | With EFS | Without EFS | With EFS |
| Mean | 835.3 | 612.6 | 4,665 | 4,664 | 4,948 | 4,948 |
| Stan Dev | 2,743.0 | 2,349.3 | 8,968 | 8,967 | 9,358 | 9,358 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 99.50% | 0.0 | 0.0 | 0.5 | 0.5 | 1.6 | 1.6 |
| 99% | 0.0 | 0.0 | 0.5 | 0.5 | 13.1 | 13.1 |
| 98% | 0.0 | 0.0 | 2.0 | 2.0 | 24.4 | 24.5 |
| 95% | 0.0 | 0.0 | 41.4 | 41.0 | 76.5 | 76.9 |
| 90% | 0.0 | 0.0 | 133.5 | 133.3 | 194.7 | 193.1 |
| 85% | 0.0 | 0.0 | 258.2 | 258.1 | 341.9 | 343.0 |
| 80% | 0.0 | 0.0 | 393.9 | 393.8 | 495.4 | 497.2 |
| 75% | 0.0 | 0.0 | 569.8 | 571.3 | 738.7 | 740.4 |
| 70% | 0.0 | 0.0 | 1,007 | 1,011 | 1,218 | 1,217 |
| 60% | 0.0 | 0.0 | 1,757 | 1,754 | 1,929 | 1,925 |
| 50% | 75.2 | 0.0 | 2,278 | 2,276 | 2,414 | 2,414 |
| 40% | 211.1 | 38.8 | 2,481 | 2,482 | 2,681 | 2,687 |
| 30% | 413.6 | 151.5 | 3,574 | 3,577 | 3,820 | 3,827 |
| 25% | 584.4 | 296.0 | 4,611 | 4,607 | 4,982 | 4,981 |
| 20% | 841.5 | 511.9 | 6,094 | 6,097 | 6,577 | 6,584 |
| 15% | 1,236 | 880.9 | 8,233 | 8,222 | 8,751 | 8,744 |
| 10% | 2,027 | 1,507 | 11,406 | 11,412 | 12,114 | 12,100 |
| 5% | 3,767 | 2,900 | 18,092 | 18,127 | 18,684 | 18,676 |
| 2% | 7,501 | 6,063 | 29,185 | 29,215 | 29,803 | 29,730 |
| 1% | 11,793 | 9,494 | 40,265 | 40,265 | 42,342 | 42,341 |
| 0.50% | 17,167 | 13,819 | 57,653 | 57,654 | 59,617 | 59,630 |
| Maximum | 100,118 | 101,251 | 229,785 | 229,785 | 241,981 | 241,981 |

## 9.2 Evaluation of Environmental Flow Standard Effects

SB3 environmental flow standards are assigned priorities based on the date that the BBEST submits its recommendation report to the TCEQ. The SB3 EFS do not affect senior water rights already in existence. The SB3 EFS protect river flow regimes from being adversely affected by future water right permit applicants.

This chapter includes a comparison of the effects of hypothetically assigning the SB3 EFS the most senior priorities in the WAMs versus the most junior priorities. The effects of EFS priorities are evaluated in a river through the comparison of the alterations between naturalized and regulated flows with EFS assigned the most senior and junior priorities. The alterations between both the flows with the different priorities are measured by two different methods, the DHRAM method and annual mean flow duration curve. The control points where SB3 EFSs were incorporated are chosen for the comparison of flow alterations because flow alterations at the control points with EFSs are more apparent than others.

### 9.2.1 Sabine WAM

The daily Sabine WAM has a priority number of 50000000 for assigning the SB3 EFSs to make them junior to all other water rights in the water right modeling (Wurbs *et al.*, 2014a). The priority number was changed to a priority number of 170000000 for making the assumed Sabine WAM in which SB3 EFSs have a senior priority to all other water rights. This assumed WRAP model for the Sabine WAM that has a senior priority to all other water rights re-computes the regulated flows.

The DHRAM method quantifies the alterations between the naturalized and regulated flows that are computed by the WRAP model at the five control points. In the section 8.1.2, the alterations between the naturalized and regulated flows, computed by the original WRAP model, were quantified by the DHRAM method at the four control points except for the control point 29500. In this section, the DHRAM quantifies both the alterations at the control point 29500. Table 9.19 summarizes the totals of impact points at the five control points to easily compare both the hydrologic alterations between the naturalized and two different regulated flows. The results of the DHRAM analyses indicate that SB3 EFSs slightly reduce the impacts on the river flows at two of the five sites from existing human influences, but the effects are imperceptible. The results of the DHRAM analyses at the five control points are presented in Tables 9.20 to 9.24.

Table 9.19 A Total of Impact Points on DHRAM Analyses in the Sabine River Basin

| Control Point | Total of Impact Points | |
|---|---|---|
| | Junior Priority (50000000) (Naturalized vs. Regulated) | Senior Priority (17000000) (Naturalized vs. Regulated) |
| BSBS | 0 | 0 |
| SRGW | 9 | 9 |
| SRBE | 10 | 9 |
| 29500 | 0 | 0 |
| SRRL | 11 | 10 |

The annual median values at the five control points are extracted from the naturalized and two different regulated flows under SB3 EFSs with a junior and a senior priority to all other water rights. The three duration curves are plotted to compare the hydrologic states of each flow for the period 1940-2013 at the five control points.

Table 9.20 DHRAM results at Control Point BSBS (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

Control Point: BSBS Period: 1940-2013

| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 238.4 | 0.8167 | 234.8 | 0.8375 | | 1.5% | 2.5% |
| February | 284.5 | 0.6652 | 280.8 | 0.6857 | | 1.3% | 3.1% |
| March | 304 | 0.8101 | 299.2 | 0.8344 | | 1.6% | 3.0% |
| April | 286.3 | 0.883 | 281.5 | 0.9012 | | 1.7% | 2.1% |
| May | 283.2 | 0.8972 | 278.3 | 0.9212 | | 1.7% | 2.7% |
| June | 170.5 | 0.9918 | 163.8 | 1.034 | | 3.9% | 4.3% |
| July | 85.66 | 1.305 | 79.99 | 1.386 | | 6.6% | 6.2% |
| August | 36.92 | 0.9991 | 33.44 | 1.024 | | 9.4% | 2.5% |
| September | 59.45 | 1.452 | 55.63 | 1.54 | | 6.4% | 6.1% |
| October | 97.84 | 1.95 | 93.47 | 2.048 | | 4.5% | 5.0% |
| November | 155.7 | 1.174 | 149 | 1.232 | | 4.3% | 4.9% |
| December | 235.8 | 0.8424 | 230.3 | 0.8685 | | 2.3% | 3.1% |
| | | | | | Average | 3.8% | 3.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 7.218 | 1.005 | 6.662 | 0.9177 | | 7.7% | 8.7% |
| 3-day minimum | 7.844 | 0.9778 | 7.198 | 0.8905 | | 8.2% | 8.9% |
| 7-day minimum | 8.934 | 0.9385 | 8.085 | 0.858 | | 9.5% | 8.6% |
| 30-day minimum | 17.35 | 0.6844 | 15.59 | 0.6467 | | 10.1% | 5.5% |
| 90-day minimum | 36.33 | 0.7197 | 33.07 | 0.729 | | 9.0% | 1.3% |
| 1-day maximum | 2413 | 0.5878 | 2396 | 0.5935 | | 0.7% | 1.0% |
| 3-day maximum | 2137 | 0.6097 | 2121 | 0.6149 | | 0.7% | 0.9% |
| 7-day maximum | 1505 | 0.6067 | 1495 | 0.6128 | | 0.7% | 1.0% |
| 30-day maximum | 660.2 | 0.509 | 656.1 | 0.5173 | | 0.6% | 1.6% |
| 90-day maximum | 400.7 | 0.4952 | 396.6 | 0.5065 | | 1.0% | 2.3% |
| | | | | | Average | 4.8% | 4.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 204.7 | 0.2539 | 197.4 | 0.2411 | | 3.6% | 5.0% |
| Date of maximum | 148.4 | 0.3181 | 145.1 | 0.3121 | | 2.2% | 1.9% |
| | | | | | Average | 2.9% | 3.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8.635 | 0.5587 | 9.338 | 0.4999 | | 8.1% | 10.5% |
| Low pulse duration | 11.07 | 0.5347 | 9.633 | 0.4534 | | 13.0% | 15.2% |
| High pulse count | 5.676 | 0.5855 | 5.527 | 0.5878 | | 2.6% | 0.4% |
| High pulse duration | 4.625 | 0.3475 | 4.71 | 0.3379 | | 1.8% | 2.8% |
| | | | | | Average | 6.4% | 7.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 107.8 | 0.6271 | 111.8 | 0.6149 | | 3.7% | 1.9% |
| Fall rate | -36.28 | -0.5553 | -38.36 | -0.5406 | | 5.7% | 2.6% |
| Number of reversals | 98.69 | 0.156 | 93.09 | 0.1603 | | 5.7% | 2.8% |
| | | | | | Average | 5.0% | 2.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.21 DHRAM results at Control Point SRGW (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | SRGW | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 2425 | 0.9114 | 1718 | 0.8795 | | 29.2% | 3.5% |
| February | 2988 | 0.8102 | 1996 | 0.8129 | | 33.2% | 0.3% |
| March | 3184 | 0.8404 | 2149 | 0.912 | | 32.5% | 8.5% |
| April | 3140 | 1.137 | 2233 | 1.339 | | 28.9% | 17.8% |
| May | 3899 | 1.058 | 2653 | 1.096 | | 32.0% | 3.6% |
| June | 2442 | 1.221 | 1674 | 1.353 | | 31.4% | 10.8% |
| July | 801.1 | 1.719 | 514.4 | 1.659 | | 35.8% | 3.5% |
| August | 270 | 1.56 | 173.7 | 1.867 | | 35.7% | 19.7% |
| September | 480.3 | 1.646 | 289.5 | 1.563 | | 39.7% | 5.0% |
| October | 1184 | 2.126 | 670.3 | 1.976 | | 43.4% | 7.1% |
| November | 1758 | 1.341 | 1115 | 1.395 | | 36.6% | 4.0% |
| December | 2645 | 1.058 | 1749 | 1.105 | | 33.9% | 4.4% |
| | | | | | Average | 34.3% | 7.4% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 35.75 | 1.237 | 0.08108 | 5.306 | | 99.8% | 328.9% |
| 3-day minimum | 37.57 | 1.22 | 9.788 | 1.461 | | 73.9% | 19.8% |
| 7-day minimum | 41.84 | 1.189 | 18.55 | 1.353 | | 55.7% | 13.8% |
| 30-day minimum | 82.65 | 1.085 | 46.13 | 1.206 | | 44.2% | 11.2% |
| 90-day minimum | 247.8 | 0.9685 | 152.6 | 0.9799 | | 38.4% | 1.2% |
| 1-day maximum | 16970 | 0.6045 | 13030 | 0.7049 | | 23.2% | 16.6% |
| 3-day maximum | 15940 | 0.6093 | 11530 | 0.7356 | | 27.7% | 20.7% |
| 7-day maximum | 14330 | 0.6179 | 9911 | 0.7506 | | 30.8% | 21.5% |
| 30-day maximum | 8461 | 0.5885 | 5738 | 0.6663 | | 32.2% | 13.2% |
| 90-day maximum | 4929 | 0.5464 | 3318 | 0.603 | | 32.7% | 10.4% |
| | | | | | Average | 45.9% | 45.7% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 255.4 | 0.1017 | 103 | 0.225 | | 59.7% | 121.2% |
| Date of maximum | 162.1 | 0.3099 | 162.5 | 0.3037 | | 0.2% | 2.0% |
| | | | | | Average | 30.0% | 61.6% |
| | | | | | Score | 2 | 2 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.946 | 0.4854 | 9.865 | 0.3835 | | 150.0% | 21.0% |
| Low pulse duration | 26.22 | 0.7151 | 10.41 | 0.6772 | | 60.3% | 5.3% |
| High pulse count | 2.919 | 0.6728 | 4.878 | 0.6446 | | 67.1% | 4.2% |
| High pulse duration | 12.68 | 0.5818 | 6.703 | 0.6257 | | 47.1% | 7.5% |
| | | | | | Average | 81.1% | 9.5% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.4 | 0.5222 | 398 | 0.5021 | | 20.5% | 3.8% |
| Fall rate | -194.4 | -0.5095 | -250.2 | -0.4832 | | 28.7% | 5.2% |
| Number of reversals | 56.82 | 0.1528 | 127.5 | 0.1249 | | 124.4% | 18.3% |
| | | | | | Average | 57.9% | 9.1% |
| | | | | | Score | 1 | 0 |

| | | |
|---|---|---|
| Total Point | | 9 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 9.22 DHRAM results at Control Point SRBE (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | SRBE | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 3514 | 0.8648 | 2588 | 0.8739 | | 26.4% | 1.1% |
| February | 4193 | 0.7109 | 3008 | 0.7388 | | 28.3% | 3.9% |
| March | 4257 | 0.7737 | 3013 | 0.8442 | | 29.2% | 9.1% |
| April | 4005 | 1.036 | 2978 | 1.248 | | 25.6% | 20.5% |
| May | 4904 | 1.015 | 3424 | 1.05 | | 30.2% | 3.4% |
| June | 3215 | 1.085 | 2314 | 1.202 | | 28.0% | 10.8% |
| July | 1117 | 1.389 | 727.5 | 1.429 | | 34.9% | 2.9% |
| August | 424 | 1.401 | 272.4 | 1.677 | | 35.8% | 19.7% |
| September | 663.5 | 1.541 | 414.4 | 1.508 | | 37.5% | 2.1% |
| October | 1471 | 2.012 | 901.9 | 1.969 | | 38.7% | 2.1% |
| November | 2325 | 1.23 | 1546 | 1.267 | | 33.5% | 3.0% |
| December | 3384 | 0.9509 | 2292 | 1.006 | | 32.3% | 5.8% |
| | | | | | Average | 31.7% | 7.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 76.84 | 0.9809 | 3.135 | 3.69 | | 95.9% | 276.2% |
| 3-day minimum | 80.32 | 0.9697 | 20.45 | 1.517 | | 74.5% | 56.4% |
| 7-day minimum | 88.92 | 0.9438 | 38.84 | 1.068 | | 56.3% | 13.2% |
| 30-day minimum | 150.3 | 0.9023 | 79.26 | 0.9334 | | 47.3% | 3.4% |
| 90-day minimum | 399.5 | 0.9217 | 245.4 | 0.9557 | | 38.6% | 3.7% |
| 1-day maximum | 17110 | 0.5888 | 13600 | 0.6452 | | 20.5% | 9.6% |
| 3-day maximum | 16510 | 0.5971 | 12760 | 0.6579 | | 22.7% | 10.2% |
| 7-day maximum | 15230 | 0.6145 | 11390 | 0.6755 | | 25.2% | 9.9% |
| 30-day maximum | 10060 | 0.582 | 7206 | 0.634 | | 28.4% | 8.9% |
| 90-day maximum | 6261 | 0.5175 | 4451 | 0.5651 | | 28.9% | 9.2% |
| | | | | | Average | 43.8% | 40.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 252.3 | 0.1018 | 146.4 | 0.2251 | | 42.0% | 121.1% |
| Date of maximum | 153.7 | 0.3076 | 149.4 | 0.3003 | | 2.8% | 2.4% |
| | | | | | Average | 22.4% | 61.7% |
| | | | | | Score | 2 | 2 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.527 | 0.5828 | 8.189 | 0.5019 | | 132.2% | 13.9% |
| Low pulse duration | 33.34 | 0.8444 | 13.17 | 0.7524 | | 60.5% | 10.9% |
| High pulse count | 3.054 | 0.7085 | 4.703 | 0.6931 | | 54.0% | 2.2% |
| High pulse duration | 14.47 | 0.5802 | 7.974 | 0.589 | | 44.9% | 1.5% |
| | | | | | Average | 72.9% | 7.1% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.4 | 0.5169 | 410.3 | 0.4866 | | 24.2% | 5.9% |
| Fall rate | -202 | -0.5119 | -275.7 | -0.4646 | | 36.5% | 9.2% |
| Number of reversals | 56.39 | 0.1386 | 119.5 | 0.1103 | | 111.9% | 20.4% |
| | | | | | Average | 57.5% | 11.8% |
| | | | | | Score | 1 | 0 |

| | | |
|---|---|---|
| Total Point | | 9 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 9.23 DHRAM results at Control Point 29500 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | 29500 | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 286.7 | 0.797 | 286.7 | 0.797 | | 0.0% | 0.0% |
| February | 305.8 | 0.7578 | 305.8 | 0.7578 | | 0.0% | 0.0% |
| March | 261.4 | 0.6793 | 261.4 | 0.6793 | | 0.0% | 0.0% |
| April | 256.5 | 0.7487 | 256.5 | 0.7487 | | 0.0% | 0.0% |
| May | 176.7 | 1.08 | 176.7 | 1.08 | | 0.0% | 0.0% |
| June | 213.4 | 1.086 | 213.4 | 1.086 | | 0.0% | 0.0% |
| July | 166.6 | 1.337 | 166.6 | 1.337 | | 0.0% | 0.0% |
| August | 103.9 | 1.131 | 103.9 | 1.131 | | 0.0% | 0.0% |
| September | 88.77 | 1.346 | 88.77 | 1.346 | | 0.0% | 0.0% |
| October | 108.4 | 1.196 | 108.4 | 1.196 | | 0.0% | 0.0% |
| November | 133.2 | 1 | 133.2 | 1 | | 0.0% | 0.0% |
| December | 221.3 | 0.8691 | 221.3 | 0.8691 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 5.784 | 1.167 | 5.78 | 1.17 | | 0.0% | 0.0% |
| 3-day minimum | 6.126 | 1.149 | 6.13 | 1.15 | | 0.0% | 0.0% |
| 7-day minimum | 6.942 | 1.14 | 6.94 | 1.14 | | 0.0% | 0.0% |
| 30-day minimum | 17.06 | 1.082 | 17.06 | 1.08 | | 0.0% | 0.0% |
| 90-day minimum | 55.91 | 0.7298 | 55.91 | 0.73 | | 0.0% | 0.0% |
| 1-day maximum | 3535 | 0.8368 | 3535 | 0.84 | | 0.0% | 0.0% |
| 3-day maximum | 2012 | 0.6841 | 2012 | 0.68 | | 0.0% | 0.0% |
| 7-day maximum | 1219 | 0.5975 | 1219 | 0.60 | | 0.0% | 0.0% |
| 30-day maximum | 594.7 | 0.4491 | 595 | 0.45 | | 0.0% | 0.0% |
| 90-day maximum | 370.5 | 0.4468 | 371 | 0.45 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 195.6 | 0.2556 | 195.6 | 0.2556 | | 0.0% | 0.0% |
| Date of maximum | 156.1 | 0.3029 | 156.1 | 0.3029 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8 | 0.5379 | 8 | 0.5379 | | 0.0% | 0.0% |
| Low pulse duration | 12.49 | 0.5924 | 12.49 | 0.5924 | | 0.0% | 0.0% |
| High pulse count | 7.176 | 0.6061 | 7.176 | 0.6061 | | 0.0% | 0.0% |
| High pulse duration | 2.999 | 0.7261 | 2.999 | 0.7261 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 186.1 | 1.025 | 186.1 | 1.025 | | 0.0% | 0.0% |
| Fall rate | -53.97 | -0.676 | -53.97 | -0.676 | | 0.0% | 0.0% |
| Number of reversals | 107.1 | 0.1438 | 107.1 | 0.1438 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.23 (Continued)

| Control Point: | 29500 | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 286.7 | 0.797 | 286.7 | 0.797 | | 0.0% | 0.0% |
| February | 305.8 | 0.7578 | 305.8 | 0.7578 | | 0.0% | 0.0% |
| March | 261.4 | 0.6793 | 261.4 | 0.6793 | | 0.0% | 0.0% |
| April | 256.5 | 0.7487 | 256.5 | 0.7487 | | 0.0% | 0.0% |
| May | 176.7 | 1.08 | 176.7 | 1.08 | | 0.0% | 0.0% |
| June | 213.4 | 1.086 | 213.4 | 1.086 | | 0.0% | 0.0% |
| July | 166.6 | 1.337 | 166.6 | 1.337 | | 0.0% | 0.0% |
| August | 103.9 | 1.131 | 103.9 | 1.131 | | 0.0% | 0.0% |
| September | 88.77 | 1.346 | 88.77 | 1.346 | | 0.0% | 0.0% |
| October | 108.4 | 1.196 | 108.4 | 1.196 | | 0.0% | 0.0% |
| November | 133.2 | 1 | 133.2 | 1 | | 0.0% | 0.0% |
| December | 221.3 | 0.8691 | 221.3 | 0.8691 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 5.784 | 1.167 | 5.784 | 1.167 | | 0.0% | 0.0% |
| 3-day minimum | 6.126 | 1.149 | 6.126 | 1.149 | | 0.0% | 0.0% |
| 7-day minimum | 6.942 | 1.14 | 6.942 | 1.14 | | 0.0% | 0.0% |
| 30-day minimum | 17.06 | 1.082 | 17.06 | 1.082 | | 0.0% | 0.0% |
| 90-day minimum | 55.91 | 0.7298 | 55.91 | 0.7298 | | 0.0% | 0.0% |
| 1-day maximum | 3535 | 0.8368 | 3535 | 0.8368 | | 0.0% | 0.0% |
| 3-day maximum | 2012 | 0.6841 | 2012 | 0.6841 | | 0.0% | 0.0% |
| 7-day maximum | 1219 | 0.5975 | 1219 | 0.5975 | | 0.0% | 0.0% |
| 30-day maximum | 594.7 | 0.4491 | 594.7 | 0.4491 | | 0.0% | 0.0% |
| 90-day maximum | 370.5 | 0.4468 | 370.5 | 0.4468 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 195.6 | 0.2556 | 195.6 | 0.2556 | | 0.0% | 0.0% |
| Date of maximum | 156.1 | 0.3029 | 156.1 | 0.3029 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8 | 0.5379 | 8 | 0.5379 | | 0.0% | 0.0% |
| Low pulse duration | 12.49 | 0.5924 | 12.49 | 0.5924 | | 0.0% | 0.0% |
| High pulse count | 7.176 | 0.6061 | 7.176 | 0.6061 | | 0.0% | 0.0% |
| High pulse duration | 2.999 | 0.7261 | 2.999 | 0.7261 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 186.1 | 1.025 | 186.1 | 1.025 | | 0.0% | 0.0% |
| Fall rate | -53.97 | -0.676 | -53.97 | -0.676 | | 0.0% | 0.0% |
| Number of reversals | 107.1 | 0.1438 | 107.1 | 0.1438 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 0 |
| Classification | | 1 |
| note: | Un-impacted condition | |

Table 9.24 DHRAM results at Control Point SRRL (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | SRRL | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 13120 | 0.7497 | 8452 | 1.075 | | 35.6% | 43.4% |
| February | 14690 | 0.578 | 10070 | 0.7913 | | 31.4% | 36.9% |
| March | 13140 | 0.6133 | 9180 | 0.8016 | | 30.1% | 30.7% |
| April | 12510 | 0.7303 | 8675 | 0.9911 | | 30.7% | 35.7% |
| May | 11740 | 0.9706 | 7587 | 1.319 | | 35.4% | 35.9% |
| June | 8696 | 0.925 | 5785 | 1.279 | | 33.5% | 38.3% |
| July | 4722 | 1.278 | 3036 | 1.719 | | 35.7% | 34.5% |
| August | 2270 | 1.13 | 1417 | 1.33 | | 37.6% | 17.7% |
| September | 2523 | 1.212 | 1518 | 1.435 | | 39.8% | 18.4% |
| October | 4069 | 1.49 | 2053 | 1.671 | | 49.5% | 12.1% |
| November | 6420 | 1.156 | 3302 | 1.593 | | 48.6% | 37.8% |
| December | 10280 | 0.8322 | 5936 | 1.17 | | 42.3% | 40.6% |
| | | | | | Average | 37.5% | 31.8% |
| | | | | | Score | 1 | 1 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 646.9 | 0.74 | 15.84 | 3.349 | | 97.6% | 352.6% |
| 3-day minimum | 660.6 | 0.7401 | 78.33 | 1.405 | | 88.1% | 89.8% |
| 7-day minimum | 692.8 | 0.7343 | 190.4 | 1.277 | | 72.5% | 73.9% |
| 30-day minimum | 926.3 | 0.7261 | 428.4 | 0.7776 | | 53.8% | 7.1% |
| 90-day minimum | 1768 | 0.7263 | 884.2 | 0.71 | | 50.0% | 2.2% |
| 1-day maximum | 45300 | 0.5594 | 36530 | 0.6521 | | 19.4% | 16.6% |
| 3-day maximum | 42360 | 0.5417 | 33710 | 0.643 | | 20.4% | 18.7% |
| 7-day maximum | 37480 | 0.5058 | 29130 | 0.6399 | | 22.3% | 26.5% |
| 30-day maximum | 25840 | 0.4848 | 19520 | 0.6592 | | 24.5% | 36.0% |
| 90-day maximum | 17500 | 0.44 | 12470 | 0.634 | | 28.7% | 44.1% |
| | | | | | Average | 47.7% | 66.7% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 261.6 | 0.1064 | 162 | 0.2997 | | 38.1% | 181.7% |
| Date of maximum | 65.57 | 0.2011 | 72.11 | 0.2139 | | 10.0% | 6.4% |
| | | | | | Average | 24.0% | 94.0% |
| | | | | | Score | 2 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.446 | 0.602 | 8.203 | 0.4792 | | 235.4% | 20.4% |
| Low pulse duration | 44.17 | 0.6551 | 12.05 | 0.6647 | | 72.7% | 1.5% |
| High pulse count | 3.176 | 0.6961 | 3.041 | 0.7413 | | 4.3% | 6.5% |
| High pulse duration | 14.4 | 0.6013 | 13.65 | 0.6819 | | 5.2% | 13.4% |
| | | | | | Average | 79.4% | 10.4% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 947.3 | 0.5524 | 866.1 | 0.5678 | | 8.6% | 2.8% |
| Fall rate | -479.8 | -0.5361 | -552.6 | -0.5083 | | 15.2% | 5.2% |
| Number of reversals | 58.31 | 0.153 | 87.72 | 0.1715 | | 50.4% | 12.1% |
| | | | | | Average | 24.7% | 6.7% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 10 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Figure 9.1 shows that the three different flows have similar hydrologic states at the control point BSBS. The regulated flow with the senior priority gets more similar to the naturalized flow than the regulated flow with the junior priority, but it is not apparent.

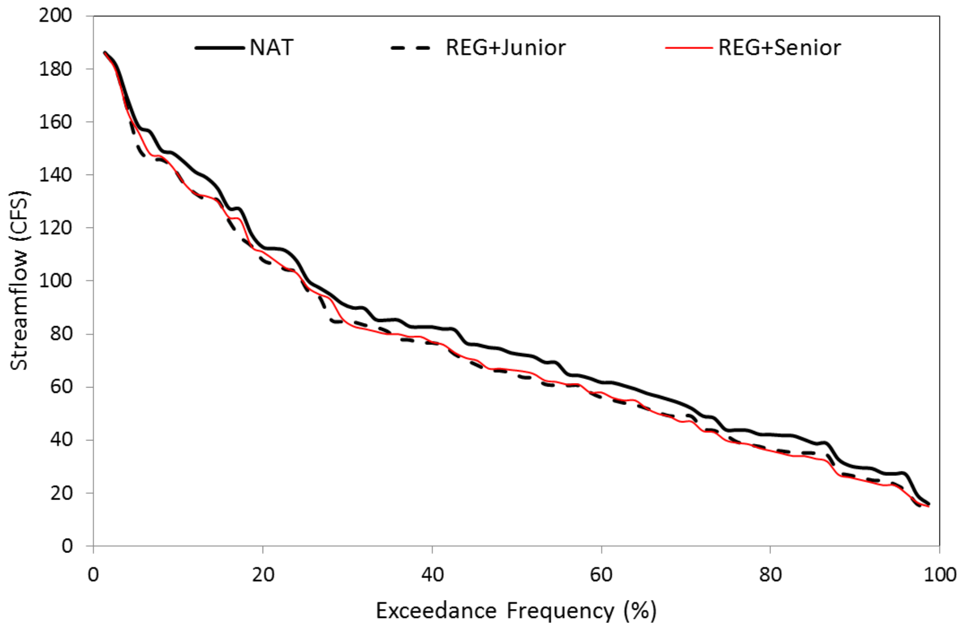



Figure 9.1 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point BSBS

Figure 9.2 presents the hydrologic states of the three different flows at the control point SRGW. The annual median values of regulated flows with the junior or senior priorities decrease than the naturalized flow. The engaged flows by SB3 EFS are based on the regulated flows at the previous day. Thus, if the naturalized flows are bigger than the engaged flows at a control point, the remainder flows after meeting SB EFS are available for other water rights at the control point and other control points. This is the reason why the hydrologic state of the naturalized flow is different from the regulated flow with SB3 EFS.

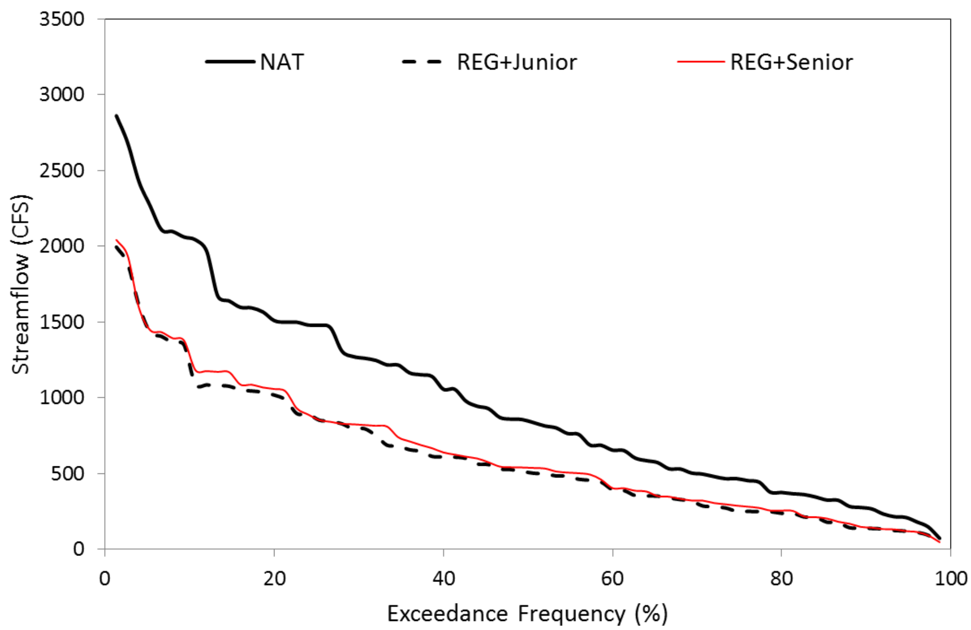



Figure 9.2 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point SRGW

Figure 9.3 shows the hydrologic states of the three different flows at the control point SRBE. The flow duration curves are very similar to the curves at the control points SRGW. The EFS with the senior priority slightly restores the regulated flow to the naturalized flow than with the junior priority, but it is also insignificant.

Figure 9.4 presents the hydrologic states of the three different flows at the control point SRBE. The three flow duration curves are almost same. That means that the river flow at the control point doesn't have serious human influences.

Figure 9.5 exhibits the hydrologic states of the three different flows at the control point SRBE. The hydrologic states of the naturalized flow are totally different from the two different regulated flows, but the two regulated flows are almost identical. This indicates that the effects of SB3 EFS are limited at the control point SRRL.

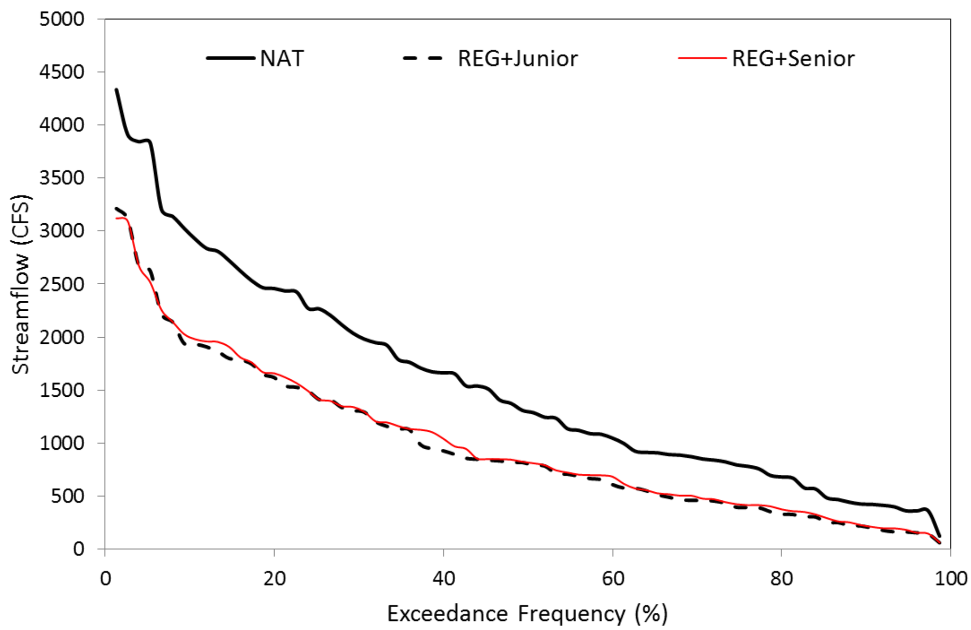



Figure 9.3 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point SRBE

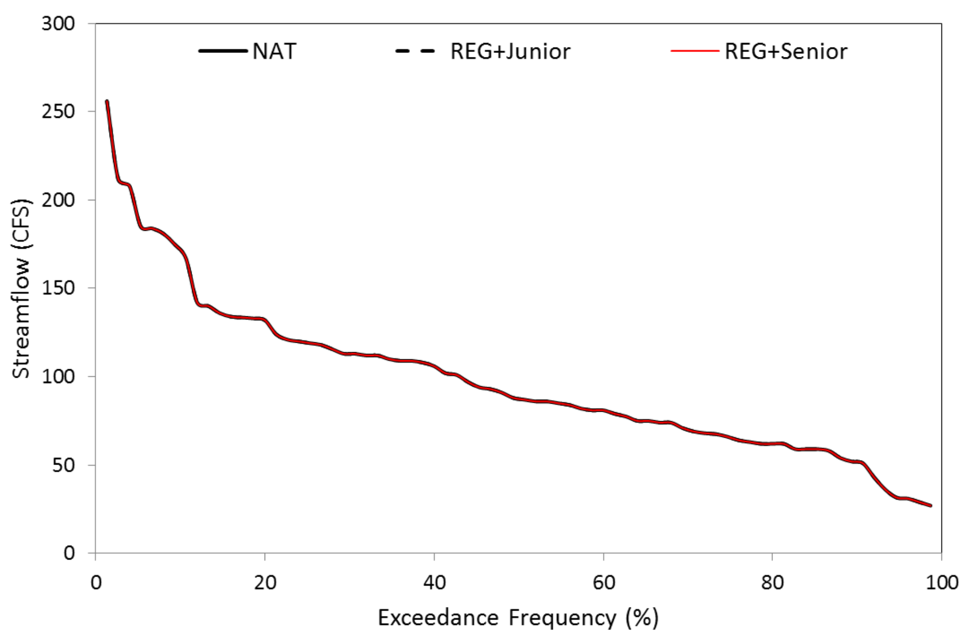



Figure 9.4 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point 29500

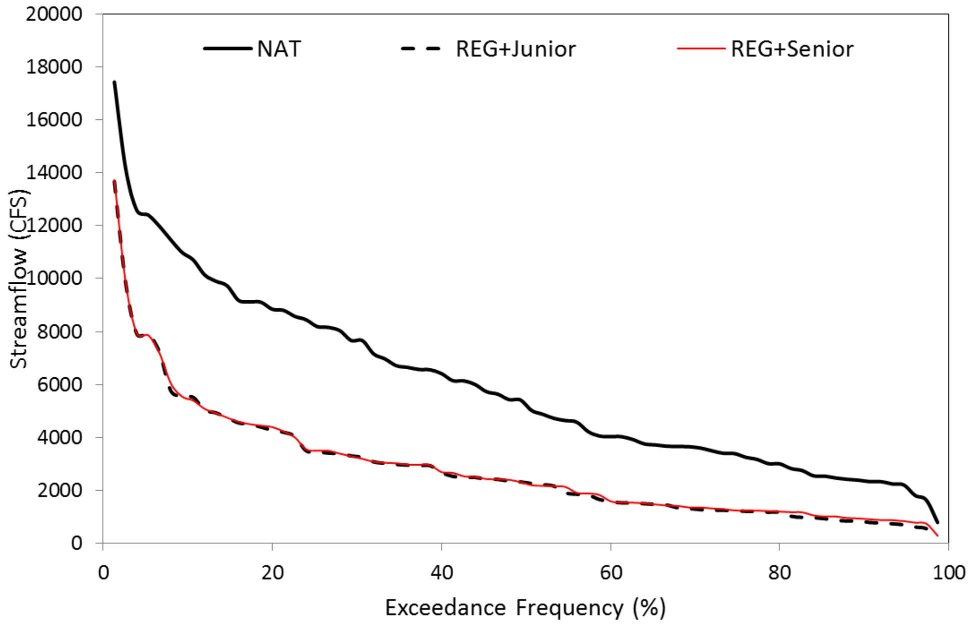



Figure 9.5 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point SRRL

### 9.2.2 Neches WAM

The Neches WAM has a priority number of 20091130 for assigning the SB3 EFSs reflecting the date that the BBEST recommendations were submitted to the TCEQ. The EFS are junior to all other water rights in WAM (Wurbs *et al.*, 2014b). The priority number was changed to 190000000 for making the hypothetical Neches WAM in which SB3 EFSs have a senior priority to all other water rights. This assumed WRAP model for the Neches WAM, incorporating SB3 EFSs that has a senior priority to all other water rights, re-computes the regulated flows.

The DHRAM method quantifies the alterations between the naturalized and regulated flows that are computed by the assumed WRAP model at the five control points. In the section 8.1.2, the alterations between the naturalized and regulated flows, computed by the original WRAP model, were quantified by the DHRAM method at the four control points except for the control point ANAL. In this section, the DHRAM quantifies both the alterations at the control point ANAL. Table 9.25 summarizes the totals of impact points at the five controls to easily compare both the hydrologic alterations between the naturalized and two different regulated flows.

The results of the DHRAM analyses indicate that SB3 EFSs slightly reduce the impacts on the river flows at three of the five sites from existing human influences, but the effects are imperceptible. SB3 EFS with a senior priority degenerate the flow regime at the control point NEEV. The results of the DHRAM analyses at the five control points are presented in Tables 9.26 to 9.30.

Table 9.25 A Total of Impact Points on DHRAM Analyses in the Neches River Basin

| Control Point | Total of Impact Points | |
|---|---|---|
| | Junior Priority (20091130) (Naturalized vs. Regulated) | Senior Priority (19000000) (Naturalized vs. Regulated) |
| NENE | 6 | 5 |
| NERO | 5 | 4 |
| ANAL | 2 | 1 |
| NEEV | 11 | 12 |
| VIKO | 0 | 0 |

The annual median values at the five control points are extracted from the naturalized and two different regulated flows under SB3 EFSs with a junior and a senior priority to all other water rights. The three duration curves are plotted to compare the hydrologic states of each flow for the period 1940-2013 at the five control points.

Table 9.26 DHRAM results at Control Point NENE (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | NENE | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1015 | 0.8536 | 608.3 | 0.8608 | | 40.1% | 0.8% |
| February | 1239 | 0.7049 | 737.4 | 0.7828 | | 40.5% | 11.1% |
| March | 1219 | 0.6986 | 724.1 | 0.8992 | | 40.6% | 28.7% |
| April | 1155 | 1.074 | 768.6 | 1.231 | | 33.5% | 14.6% |
| May | 1209 | 1.056 | 670.9 | 1.19 | | 44.5% | 12.7% |
| June | 726.5 | 1.156 | 401.1 | 1.177 | | 44.8% | 1.8% |
| July | 236.9 | 1.836 | 142.6 | 1.235 | | 39.8% | 32.7% |
| August | 72.4 | 1.964 | 77.15 | 1.277 | | 6.6% | 35.0% |
| September | 212.2 | 1.812 | 133.2 | 1.561 | | 37.2% | 13.9% |
| October | 446.8 | 2.142 | 256.7 | 1.693 | | 42.5% | 21.0% |
| November | 668.5 | 1.32 | 359.2 | 1.28 | | 46.3% | 3.0% |
| December | 962.4 | 0.9138 | 467.9 | 0.8749 | | 51.4% | 4.3% |
| | | | | | Average | 39.0% | 15.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 5.162 | 2.743 | 4.149 | 1.355 | | 19.6% | 50.6% |
| 3-day minimum | 5.946 | 2.855 | 10.7 | 0.7478 | | 80.0% | 73.8% |
| 7-day minimum | 8.743 | 3.286 | 14.28 | 0.7263 | | 63.3% | 77.9% |
| 30-day minimum | 24.94 | 1.804 | 34.89 | 0.5556 | | 39.9% | 69.2% |
| 90-day minimum | 93.09 | 1.407 | 76.35 | 0.8268 | | 18.0% | 41.2% |
| 1-day maximum | 7681 | 0.6525 | 5660 | 0.7907 | | 26.3% | 21.2% |
| 3-day maximum | 6887 | 0.6553 | 4590 | 0.7804 | | 33.4% | 19.1% |
| 7-day maximum | 5969 | 0.6271 | 3669 | 0.754 | | 38.5% | 20.2% |
| 30-day maximum | 3056 | 0.5362 | 1764 | 0.6708 | | 42.3% | 25.1% |
| 90-day maximum | 1773 | 0.5009 | 1027 | 0.623 | | 42.1% | 24.4% |
| | | | | | Average | 40.3% | 42.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 221.7 | 0.1533 | 178.1 | 0.3012 | | 19.7% | 96.5% |
| Date of maximum | 67.27 | 0.1753 | 71.2 | 0.1797 | | 5.8% | 2.5% |
| | | | | | Average | 12.8% | 49.5% |
| | | | | | Score | 1 | 1 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.324 | 0.4563 | 11.74 | 0.4046 | | 171.5% | 11.3% |
| Low pulse duration | 24.74 | 0.8672 | 8.626 | 0.8725 | | 65.1% | 0.6% |
| High pulse count | 4.635 | 0.6191 | 6.419 | 0.6301 | | 38.5% | 1.8% |
| High pulse duration | 7.569 | 0.4332 | 4.327 | 0.5732 | | 42.8% | 32.3% |
| | | | | | Average | 79.5% | 11.5% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 216.8 | 0.5456 | 181.7 | 0.5273 | | 16.2% | 3.4% |
| Fall rate | -114.8 | -0.5323 | -121.2 | -0.5073 | | 5.6% | 4.7% |
| Number of reversals | 52.88 | 0.2205 | 111 | 0.1559 | | 109.9% | 29.3% |
| | | | | | Average | 43.9% | 12.4% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 5 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 9.27 DHRAM results at Control Point NERO (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | NERO | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 3854 | 0.8892 | 3385 | 0.9184 | | 12.2% | 3.3% |
| February | 4158 | 0.7283 | 3641 | 0.7753 | | 12.4% | 6.5% |
| March | 3573 | 0.7663 | 2999 | 0.8497 | | 16.1% | 10.9% |
| April | 3289 | 0.9322 | 2871 | 0.9747 | | 12.7% | 4.6% |
| May | 3709 | 1.1 | 3094 | 1.207 | | 16.6% | 9.7% |
| June | 2347 | 1.105 | 1958 | 1.199 | | 16.6% | 8.5% |
| July | 1002 | 1.686 | 840.4 | 1.818 | | 16.1% | 7.8% |
| August | 305.2 | 1.549 | 258.6 | 1.62 | | 15.3% | 4.6% |
| September | 519.9 | 1.478 | 401.9 | 1.561 | | 22.7% | 5.6% |
| October | 1194 | 1.801 | 982.6 | 1.849 | | 17.7% | 2.7% |
| November | 2181 | 1.457 | 1826 | 1.524 | | 16.3% | 4.6% |
| December | 3072 | 1.081 | 2544 | 1.148 | | 17.2% | 6.2% |
| | | | | | Average | 16.0% | 6.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 45.64 | 1.637 | 5.216 | 3.183 | | 88.6% | 94.4% |
| 3-day minimum | 48.16 | 1.669 | 10.66 | 1.963 | | 77.9% | 17.6% |
| 7-day minimum | 53.78 | 1.666 | 19.87 | 1.353 | | 63.1% | 18.8% |
| 30-day minimum | 98.56 | 1.526 | 66.11 | 1.602 | | 32.9% | 5.0% |
| 90-day minimum | 298.9 | 1.249 | 234 | 1.336 | | 21.7% | 7.0% |
| 1-day maximum | 17230 | 0.6091 | 15690 | 0.6069 | | 8.9% | 0.4% |
| 3-day maximum | 15990 | 0.6048 | 14450 | 0.6137 | | 9.6% | 1.5% |
| 7-day maximum | 14270 | 0.5882 | 12690 | 0.6208 | | 11.1% | 5.5% |
| 30-day maximum | 8774 | 0.5577 | 7662 | 0.6106 | | 12.7% | 9.5% |
| 90-day maximum | 5512 | 0.5299 | 4738 | 0.5802 | | 14.0% | 9.5% |
| | | | | | Average | 34.0% | 16.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 247.2 | 0.1121 | 180 | 0.2765 | | 27.2% | 146.7% |
| Date of maximum | 148.8 | 0.3018 | 150.1 | 0.2999 | | 0.9% | 0.6% |
| | | | | | Average | 14.0% | 73.6% |
| | | | | | Score | 1 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.905 | 0.5227 | 5.216 | 0.4667 | | 79.6% | 10.7% |
| Low pulse duration | 35.54 | 0.7146 | 19.75 | 0.6956 | | 44.4% | 2.7% |
| High pulse count | 3.486 | 0.7919 | 3.635 | 0.7208 | | 4.3% | 9.0% |
| High pulse duration | 11.57 | 0.6183 | 10.61 | 0.7109 | | 8.3% | 15.0% |
| | | | | | Average | 34.1% | 9.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 442.7 | 0.6301 | 416.6 | 0.6031 | | 5.9% | 4.3% |
| Fall rate | -207.3 | -0.5878 | -221.2 | -0.5595 | | 6.7% | 4.8% |
| Number of reversals | 54.27 | 0.2735 | 77.03 | 0.168 | | 41.9% | 38.6% |
| | | | | | Average | 18.2% | 15.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 4 |
| Classification | 2 |
| note: | Low risk of impact |

Table 9.28 DHRAM results at Control Point ANAL (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | ANAL | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated(Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1456 | 0.8634 | 1158 | 0.9685 | | 20.5% | 12.2% |
| February | 1643 | 0.6733 | 1282 | 0.7664 | | 22.0% | 13.8% |
| March | 1487 | 0.7317 | 1150 | 0.827 | | 22.7% | 13.0% |
| April | 1285 | 0.8509 | 961.1 | 0.9464 | | 25.2% | 11.2% |
| May | 1388 | 1.089 | 1085 | 1.209 | | 21.8% | 11.0% |
| June | 783.2 | 1.122 | 568.8 | 1.28 | | 27.4% | 14.1% |
| July | 302.2 | 1.429 | 207 | 1.511 | | 31.5% | 5.7% |
| August | 110.5 | 1.238 | 73.84 | 1.247 | | 33.2% | 0.7% |
| September | 237.8 | 1.504 | 150.8 | 1.521 | | 36.6% | 1.1% |
| October | 491.2 | 1.742 | 333.4 | 1.82 | | 32.1% | 4.5% |
| November | 883.6 | 1.365 | 643.8 | 1.542 | | 27.1% | 13.0% |
| December | 1311 | 1.086 | 1010 | 1.235 | | 23.0% | 13.7% |
| | | | | | Average | 26.9% | 9.5% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 8.134 | 1.318 | 1.368 | 2.742 | | 83.2% | 108.0% |
| 3-day minimum | 9.104 | 1.302 | 2.637 | 2.181 | | 71.0% | 67.5% |
| 7-day minimum | 11.76 | 1.259 | 4.672 | 1.783 | | 60.3% | 41.6% |
| 30-day minimum | 38.51 | 1.221 | 23.04 | 1.141 | | 40.2% | 6.6% |
| 90-day minimum | 116.2 | 1.095 | 72.18 | 1.048 | | 37.9% | 4.3% |
| 1-day maximum | 8426 | 0.6321 | 7199 | 0.6823 | | 14.6% | 7.9% |
| 3-day maximum | 7841 | 0.6279 | 6533 | 0.6811 | | 16.7% | 8.5% |
| 7-day maximum | 6895 | 0.5728 | 5677 | 0.6298 | | 17.7% | 10.0% |
| 30-day maximum | 3606 | 0.5228 | 2919 | 0.5852 | | 19.1% | 11.9% |
| 90-day maximum | 2144 | 0.4841 | 1699 | 0.5636 | | 20.8% | 16.4% |
| | | | | | Average | 38.1% | 28.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 226.5 | 0.1689 | 164.2 | 0.2571 | | 27.5% | 52.2% |
| Date of maximum | 59.08 | 0.1801 | 59.36 | 0.1829 | | 0.5% | 1.6% |
| | | | | | Average | 14.0% | 26.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.608 | 0.4186 | 6.662 | 0.3977 | | 44.6% | 5.0% |
| Low pulse duration | 20.9 | 0.6225 | 13.82 | 0.5413 | | 33.9% | 13.0% |
| High pulse count | 3.649 | 0.6811 | 3.784 | 0.6948 | | 3.7% | 2.0% |
| High pulse duration | 10.52 | 0.4969 | 9.51 | 0.5356 | | 9.6% | 7.8% |
| | | | | | Average | 22.9% | 7.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 201.9 | 0.5336 | 178.1 | 0.5418 | | 11.8% | 1.5% |
| Fall rate | -110.8 | -0.5265 | -105.4 | -0.5585 | | 4.9% | 6.1% |
| Number of reversals | 51.38 | 0.1397 | 71.3 | 0.1552 | | 38.8% | 11.1% |
| | | | | | Average | 18.5% | 6.2% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 2 |
| Classification | 2 |
| note: | Low risk of impact |

## Table 9.28 (Continued)

Control Point: ANAL Period: 1940-2013

| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1456 | 0.8634 | 1174 | 0.9477 | | 19.4% | 9.8% |
| February | 1643 | 0.6733 | 1286 | 0.7525 | | 21.7% | 11.8% |
| March | 1487 | 0.7317 | 1137 | 0.8162 | | 23.5% | 11.5% |
| April | 1285 | 0.8509 | 985.1 | 0.9076 | | 23.3% | 6.7% |
| May | 1388 | 1.089 | 1092 | 1.188 | | 21.3% | 9.1% |
| June | 783.2 | 1.122 | 572.3 | 1.262 | | 26.9% | 12.5% |
| July | 302.2 | 1.429 | 207.2 | 1.449 | | 31.4% | 1.4% |
| August | 110.5 | 1.238 | 75.45 | 1.209 | | 31.7% | 2.3% |
| September | 237.8 | 1.504 | 153.5 | 1.536 | | 35.4% | 2.1% |
| October | 491.2 | 1.742 | 334 | 1.654 | | 32.0% | 5.1% |
| November | 883.6 | 1.365 | 643.1 | 1.521 | | 27.2% | 11.4% |
| December | 1311 | 1.086 | 1011 | 1.211 | | 22.9% | 11.5% |
| | | | | | Average | 26.4% | 7.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 8.134 | 1.318 | 2.48 | 1.744 | | 69.5% | 32.3% |
| 3-day minimum | 9.104 | 1.302 | 4.518 | 1.413 | | 50.4% | 8.5% |
| 7-day minimum | 11.76 | 1.259 | 7.565 | 1.175 | | 35.7% | 6.7% |
| 30-day minimum | 38.51 | 1.221 | 25.77 | 1.003 | | 33.1% | 17.9% |
| 90-day minimum | 116.2 | 1.095 | 75.3 | 0.9895 | | 35.2% | 9.6% |
| 1-day maximum | 8426 | 0.6321 | 7002 | 0.6651 | | 16.9% | 5.2% |
| 3-day maximum | 7841 | 0.6279 | 6393 | 0.6709 | | 18.5% | 6.8% |
| 7-day maximum | 6895 | 0.5728 | 5592 | 0.6299 | | 18.9% | 10.0% |
| 30-day maximum | 3606 | 0.5228 | 2887 | 0.5678 | | 19.9% | 8.6% |
| 90-day maximum | 2144 | 0.4841 | 1689 | 0.5534 | | 21.2% | 14.3% |
| | | | | | Average | 31.9% | 12.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 226.5 | 0.1689 | 208.2 | 0.2057 | | 8.1% | 21.8% |
| Date of maximum | 59.08 | 0.1801 | 58.11 | 0.1812 | | 1.6% | 0.6% |
| | | | | | Average | 4.9% | 11.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.608 | 0.4186 | 7.149 | 0.5181 | | 55.1% | 23.8% |
| Low pulse duration | 20.9 | 0.6225 | 14.45 | 0.6125 | | 30.9% | 1.6% |
| High pulse count | 3.649 | 0.6811 | 3.649 | 0.7293 | | 0.0% | 7.1% |
| High pulse duration | 10.52 | 0.4969 | 9.829 | 0.51 | | 6.6% | 2.6% |
| | | | | | Average | 23.1% | 8.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 201.9 | 0.5336 | 170 | 0.5429 | | 15.8% | 1.7% |
| Fall rate | -110.8 | -0.5265 | -106 | -0.542 | | 4.3% | 2.9% |
| Number of reversals | 51.38 | 0.1397 | 90.28 | 0.1974 | | 75.7% | 41.3% |
| | | | | | Average | 31.9% | 15.3% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

Table 9.29 DHRAM results at Control Point NEEV (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | NEEV | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 9770 | 0.8516 | 6370 | 1.033 | | 34.8% | 21.3% |
| February | 10790 | 0.6577 | 8180 | 0.8757 | | 24.2% | 33.1% |
| March | 9273 | 0.7049 | 7575 | 0.9579 | | 18.3% | 35.9% |
| April | 8424 | 0.8106 | 6185 | 1.018 | | 26.6% | 25.6% |
| May | 8684 | 1.072 | 5784 | 1.096 | | 33.4% | 2.2% |
| June | 5928 | 1.051 | 5074 | 1.345 | | 14.4% | 28.0% |
| July | 2628 | 1.362 | 2129 | 1.564 | | 19.0% | 14.8% |
| August | 998.8 | 1.151 | 647.3 | 1.276 | | 35.2% | 10.9% |
| September | 1663 | 1.381 | 795.3 | 1.591 | | 52.2% | 15.2% |
| October | 3318 | 1.822 | 1295 | 1.608 | | 61.0% | 11.7% |
| November | 5588 | 1.398 | 3076 | 1.696 | | 45.0% | 21.3% |
| December | 7953 | 0.9712 | 5095 | 1.22 | | 35.9% | 25.6% |
| | | | | | Average | 33.3% | 20.5% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 200.9 | 1.223 | 15.66 | 3.087 | | 92.2% | 152.4% |
| 3-day minimum | 209.6 | 1.22 | 55.42 | 1.587 | | 73.6% | 30.1% |
| 7-day minimum | 227.9 | 1.201 | 91.73 | 1.213 | | 59.7% | 1.0% |
| 30-day minimum | 395.7 | 1.223 | 196.1 | 1.149 | | 50.4% | 6.1% |
| 90-day minimum | 900.5 | 1.015 | 447.8 | 0.9976 | | 50.3% | 1.7% |
| 1-day maximum | 37530 | 0.652 | 26500 | 0.6117 | | 29.4% | 6.2% |
| 3-day maximum | 35310 | 0.6293 | 24940 | 0.5836 | | 29.4% | 7.3% |
| 7-day maximum | 32120 | 0.5985 | 22930 | 0.5739 | | 28.6% | 4.1% |
| 30-day maximum | 20880 | 0.5489 | 15800 | 0.6132 | | 24.3% | 11.7% |
| 90-day maximum | 13450 | 0.5012 | 10030 | 0.6439 | | 25.4% | 28.5% |
| | | | | | Average | 46.3% | 24.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 259.4 | 0.1293 | 70.85 | 0.2867 | | 72.7% | 121.7% |
| Date of maximum | 141.2 | 0.2954 | 80.77 | 0.1839 | | 42.8% | 37.7% |
| | | | | | Average | 57.7% | 79.7% |
| | | | | | Score | 3 | 3 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 2.514 | 0.4429 | 13.04 | 0.5891 | | 418.7% | 33.0% |
| Low pulse duration | 41.43 | 0.9228 | 8.854 | 1.119 | | 78.6% | 21.3% |
| High pulse count | 2.608 | 0.7558 | 3.081 | 0.7927 | | 18.1% | 4.9% |
| High pulse duration | 16.94 | 0.6418 | 15.39 | 0.7752 | | 9.1% | 20.8% |
| | | | | | Average | 131.2% | 20.0% |
| | | | | | Score | 3 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 677.1 | 0.5428 | 627.1 | 0.4916 | | 7.4% | 9.4% |
| Fall rate | -386.8 | -0.5466 | -532.8 | -0.6333 | | 37.7% | 15.9% |
| Number of reversals | 45.53 | 0.19 | 109.4 | 0.1791 | | 140.3% | 5.7% |
| | | | | | Average | 61.8% | 10.3% |
| | | | | | Score | 1 | 0 |

| | | |
|---|---|---|
| Total Point | | 12 |
| Classification | | 4 |
| note: | High risk of impact | |

Table 9.30 DHRAM results at Control Point VIKO (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | VIKO | Period: | 1940-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1381 | 0.8871 | 1381 | 0.8874 | | 0.0% | 0.0% |
| February | 1395 | 0.7546 | 1395 | 0.7549 | | 0.0% | 0.0% |
| March | 1046 | 0.7362 | 1045 | 0.7367 | | 0.1% | 0.1% |
| April | 959.4 | 1.103 | 958.8 | 1.103 | | 0.1% | 0.0% |
| May | 1020 | 1.172 | 1020 | 1.172 | | 0.0% | 0.0% |
| June | 827.8 | 1.456 | 827.2 | 1.457 | | 0.1% | 0.1% |
| July | 532.5 | 1.415 | 531.6 | 1.416 | | 0.2% | 0.1% |
| August | 264.1 | 1.148 | 263.4 | 1.149 | | 0.3% | 0.1% |
| September | 398.1 | 1.492 | 397 | 1.494 | | 0.3% | 0.1% |
| October | 650.2 | 2.009 | 649.6 | 2.011 | | 0.1% | 0.1% |
| November | 968.2 | 1.409 | 967.6 | 1.41 | | 0.1% | 0.1% |
| December | 1170 | 0.9349 | 1170 | 0.9355 | | 0.0% | 0.1% |
| | | | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.135 | 2.893 | 2.176 | 2.849 | | 1.9% | 1.5% |
| 3-day minimum | 2.428 | 2.747 | 2.459 | 2.693 | | 1.3% | 2.0% |
| 7-day minimum | 3.714 | 2.704 | 3.739 | 2.666 | | 0.7% | 1.4% |
| 30-day minimum | 35.5 | 2.269 | 35.43 | 2.274 | | 0.2% | 0.2% |
| 90-day minimum | 162 | 1.094 | 161.4 | 1.097 | | 0.4% | 0.3% |
| 1-day maximum | 9326 | 0.684 | 9326 | 0.6841 | | 0.0% | 0.0% |
| 3-day maximum | 8566 | 0.6866 | 8565 | 0.6867 | | 0.0% | 0.0% |
| 7-day maximum | 7177 | 0.6383 | 7176 | 0.6384 | | 0.0% | 0.0% |
| 30-day maximum | 3488 | 0.6087 | 3488 | 0.6088 | | 0.0% | 0.0% |
| 90-day maximum | 1921 | 0.5368 | 1921 | 0.537 | | 0.0% | 0.0% |
| | | | | | Average | 0.4% | 0.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 200.1 | 0.2048 | 201.1 | 0.2037 | | 0.5% | 0.5% |
| Date of maximum | 59.78 | 0.2275 | 59.74 | 0.2275 | | 0.1% | 0.0% |
| | | | | | Average | 0.3% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.014 | 0.378 | 7.068 | 0.3822 | | 0.8% | 1.1% |
| Low pulse duration | 13.02 | 0.3544 | 13.01 | 0.3556 | | 0.1% | 0.3% |
| High pulse count | 4.595 | 0.705 | 4.608 | 0.7046 | | 0.3% | 0.1% |
| High pulse duration | 7.483 | 0.5295 | 7.461 | 0.5294 | | 0.3% | 0.0% |
| | | | | | Average | 0.4% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 305.8 | 0.5543 | 305.4 | 0.5557 | | 0.1% | 0.3% |
| Fall rate | -140.5 | -0.5584 | -140.5 | -0.5584 | | 0.0% | 0.0% |
| Number of reversals | 54.68 | 0.1635 | 54.76 | 0.1659 | | 0.1% | 1.5% |
| | | | | | Average | 0.1% | 0.6% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Figure 9.6 shows the hydrologic states of the three different flows at the control point NENE. The flow duration curves of the regulated flows are considerably different from the naturalized flows. But the EFS with the senior priority slightly improves the flow regimes of the regulated flows relative to with the junior priority at the control point like the result of the DHRAM analysis.

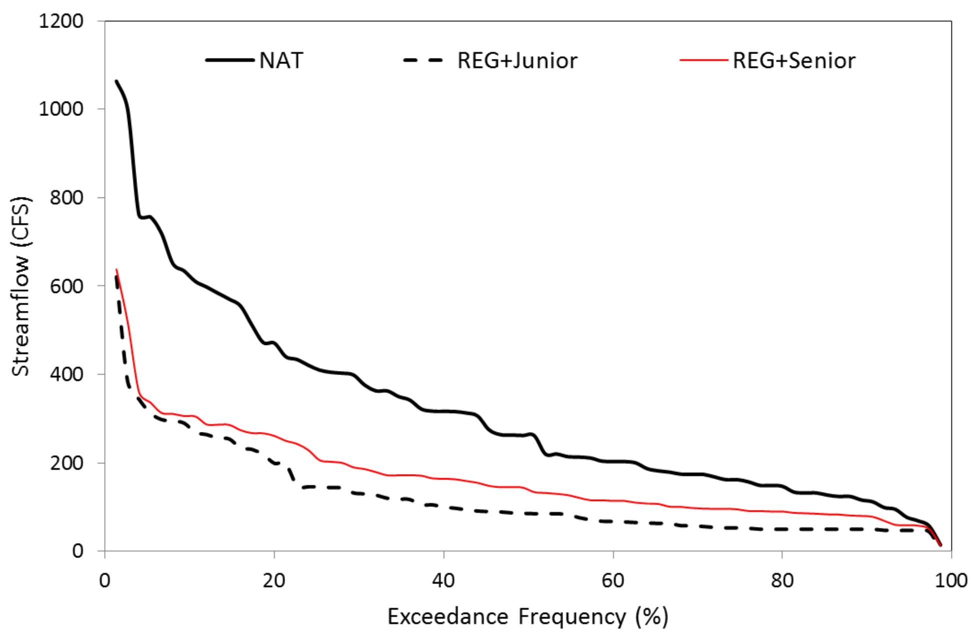



Figure 9.6 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point NENE

Figure 9.7 presents the hydrologic states of the three different flows at the control point NERO. The flow duration curves of the regulated flows are slightly different from the naturalized flows. The regulated flow seems to be slightly improved to the naturalized flow by EFS with the senior priority than with the junior priority, but it is also insignificant.

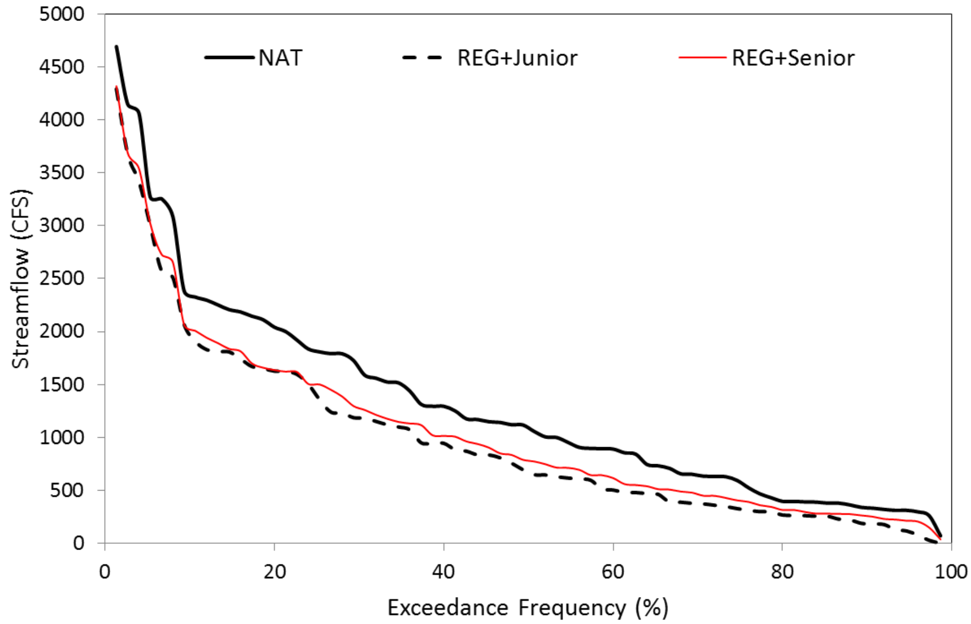



Figure 9.7 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point NERO

Figure 9.8 shows the hydrologic states of the three different flows at the control point ANAL. The flow duration curves of the regulated flows are obviously different from the naturalized flows. The regulated flow with the senior priority get closer to the naturalized flow than the flow with the junior priority, but the difference between both the regulated flows is also insignificant.

Figure 9.9 present the hydrologic states of the three different flows at the control point NEEV. The flow duration curves of both the regulated flows are obviously different from the naturalized flows. However, both duration curves of the regulated flows are almost identical. This indicates that the EFS cannot play the role to relieve the human influences on the regulated flows at the control point NEEV similar to the control point SRRL in the Sabine River Basin.

Figure 9.10 presents the hydrologic states of the three different flows at the control point VIKO. The three flow duration curves are almost identical. This means that there are no serious human influences on the river flow at the control point VIKO.

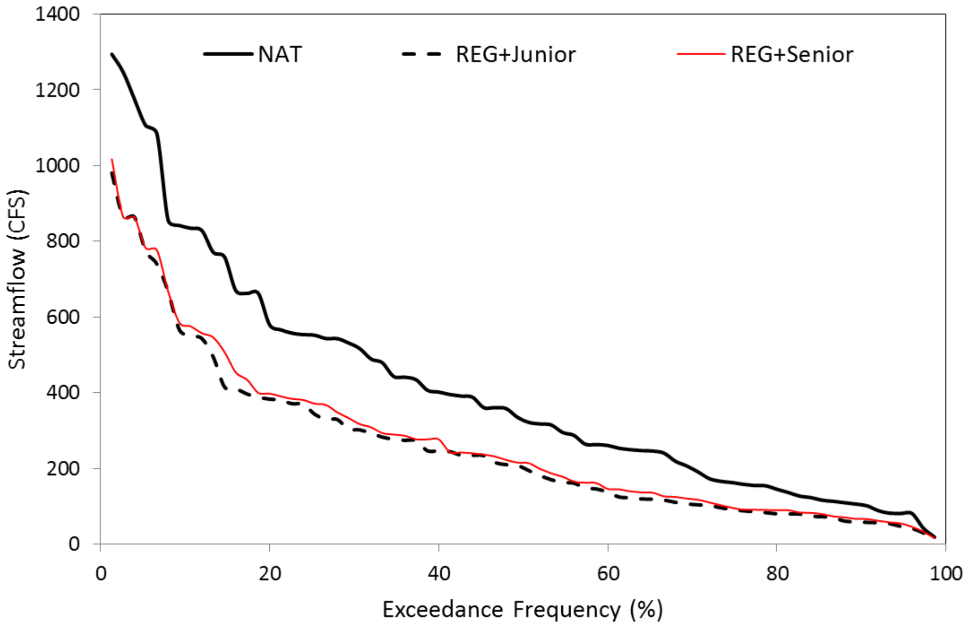



Figure 9.8 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point ANAL

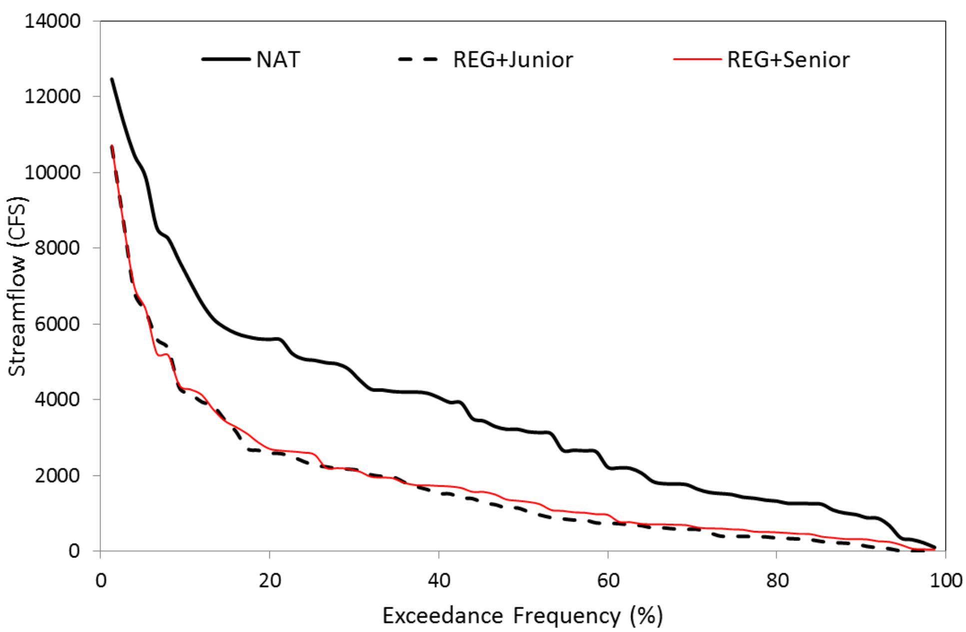



Figure 9.9 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point NEEV

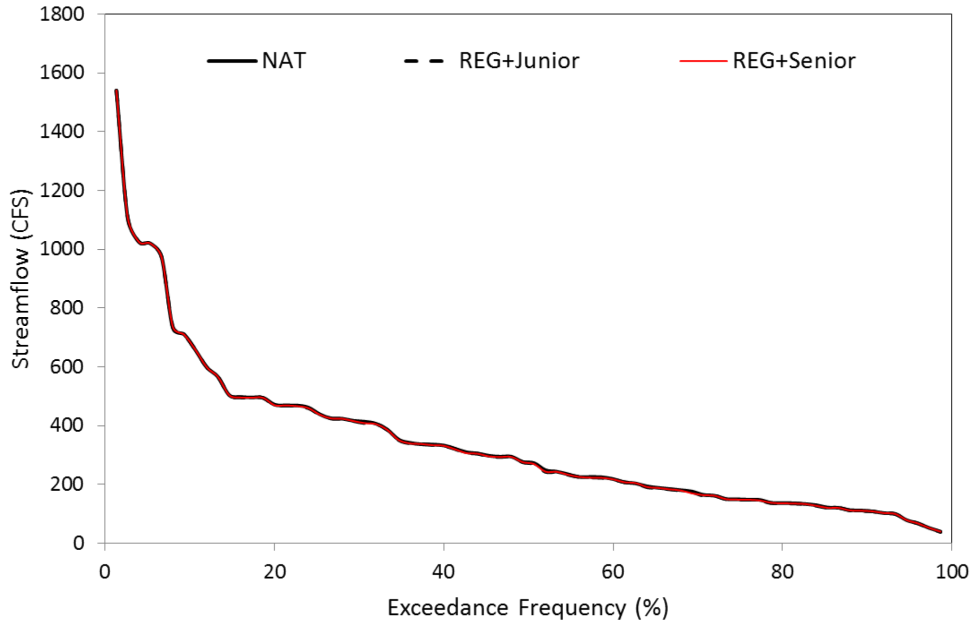


Figure 9.10 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point VIKO

### 9.2.3 GSA WAM

Daily GSA WAM has a priority number of 88888888 for assigning the SB3 EFSs to make them junior to all other water rights in the water right modeling (Wurbs *et al.*, 2014c). The priority number was changed to a priority number of 190000000 for making the assumed GSA WAM in which SB3 EFSs have a senior priority to all other water rights. This assumed WRAP model for the GSA WAM, incorporating SB3 EFSs that has a senior priority to all other water rights, re-computes the regulated flows.

The DHRAM method quantifies the alterations between the naturalized and regulated flows that are computed by the assumed WRAP model at the fifteen control points. In the section 8.1.2, the alterations between the naturalized and regulated flows, computed by the original WRAP model, were quantified by the DHRAM method at the six control points except for the nine control points CP11, C38461, CP13, CP14, P38241, CP28, CP29, CP32, and CP37. In this section, the DHRAM quantifies both the alterations at the nine control points. Table 9.31 summarizes the totals of impact points at the fifteen controls to easily compare both the hydrologic alterations between the naturalized and two different regulated flows.

Table 9.31 A Total of Impact Points on DHRAM Analyses in the GSA River Basins

| Control Point | Total of Impact Points | |
|---|---|---|
| | Junior Priority (88888888) (Naturalized vs. Regulated) | Senior Priority (19000000) (Naturalized vs. Regulated) |
| CP01 | 1 | 0 |
| CP02 | 0 | 0 |
| CP08 | 0 | 0 |
| CP10 | 1 | 0 |
| CP11 | 0 | 0 |
| C38461 | 1 | 6 |
| CP13 | 0 | 0 |
| CP14 | 0 | 5 |
| CP15 | 0 | 3 |
| P38241 | 0 | 0 |
| CP28 | 3 | 1 |
| CP29 | 6 | 1 |
| CP32 | 2 | 1 |
| CP35 | 0 | 0 |
| CP37 | 1 | 0 |

The results of the DHRAM analyses indicate that SB3 EFSs slightly reduce the impacts on the river flows at six of the fifteen sites from existing human influences, but degenerate the river flows at the three control points that are located in the Guadalupe River Basin. There are no differences between both the regulated flows at the six control points. This attributes that the six control points don’t have obvious human influences, such as water diversion and dam impoundations their upstream. The results of the DHRAM analyses at the five control points are presented in Tables 9.32 to 9.46.

Table 9.32 DHRAM results at Control Point CP01 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP01 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 157.6 | 0.8912 | 147.3 | 0.9319 | | 6.5% | 4.6% |
| February | 189.1 | 0.9158 | 177 | 0.9569 | | 6.4% | 4.5% |
| March | 184.1 | 0.836 | 171.4 | 0.8775 | | 6.9% | 5.0% |
| April | 203.7 | 1.121 | 189 | 1.189 | | 7.2% | 6.1% |
| May | 254.2 | 1.009 | 237.6 | 1.054 | | 6.5% | 4.5% |
| June | 295.7 | 1.72 | 275.4 | 1.822 | | 6.9% | 5.9% |
| July | 187.2 | 1.782 | 169.9 | 1.898 | | 9.2% | 6.5% |
| August | 187.8 | 3.015 | 171.2 | 3.244 | | 8.8% | 7.6% |
| September | 212.9 | 1.601 | 191.4 | 1.735 | | 10.1% | 8.4% |
| October | 268 | 1.327 | 252.3 | 1.376 | | 5.9% | 3.7% |
| November | 185.7 | 1.389 | 173.4 | 1.472 | | 6.6% | 6.0% |
| December | 169.9 | 1.11 | 159.2 | 1.17 | | 6.3% | 5.4% |
| | | | | | Average | 7.3% | 5.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0.5 | 1.955 | 0.4688 | 1.923 | | 6.2% | 1.6% |
| 3-day minimum | 0.6246 | 1.885 | 0.5692 | 1.812 | | 8.9% | 3.9% |
| 7-day minimum | 1.18 | 1.813 | 1.096 | 1.721 | | 7.1% | 5.1% |
| 30-day minimum | 13.06 | 1.43 | 11.28 | 1.337 | | 13.6% | 6.5% |
| 90-day minimum | 62.3 | 0.8049 | 53.87 | 0.8185 | | 13.5% | 1.7% |
| 1-day maximum | 6544 | 1.743 | 6380 | 1.772 | | 2.5% | 1.7% |
| 3-day maximum | 3550 | 1.501 | 3456 | 1.527 | | 2.6% | 1.7% |
| 7-day maximum | 2102 | 1.266 | 2043 | 1.293 | | 2.8% | 2.1% |
| 30-day maximum | 836.8 | 0.9856 | 804.6 | 1.015 | | 3.8% | 3.0% |
| 90-day maximum | 454.3 | 0.843 | 431.4 | 0.8756 | | 5.0% | 3.9% |
| | | | | | Average | 6.6% | 3.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 163.3 | 0.2483 | 161.2 | 0.2404 | | 1.3% | 3.2% |
| Date of maximum | 191.8 | 0.2314 | 187.4 | 0.2327 | | 2.3% | 0.6% |
| | | | | | Average | 1.8% | 1.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.075 | 0.4586 | 7.288 | 0.4379 | | 3.0% | 4.5% |
| Low pulse duration | 12.75 | 0.4767 | 12.57 | 0.4698 | | 1.4% | 1.4% |
| High pulse count | 2.238 | 0.7048 | 2.213 | 0.7108 | | 1.1% | 0.9% |
| High pulse duration | 3.501 | 0.8156 | 3.493 | 0.8227 | | 0.2% | 0.9% |
| | | | | | Average | 1.4% | 1.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 156.7 | 1.087 | 132 | 1.115 | | 15.8% | 2.6% |
| Fall rate | -52.06 | -1.003 | -54.92 | -1.005 | | 5.5% | 0.2% |
| Number of reversals | 61.38 | 0.1761 | 81.39 | 0.1952 | | 32.6% | 10.8% |
| | | | | | Average | 18.0% | 4.5% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.33 DHRAM results at Control Point CP02 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP02 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 301 | 1.141 | 291.1 | 1.169 | | 3.3% | 2.5% |
| February | 341.7 | 1.084 | 330.5 | 1.112 | | 3.3% | 2.6% |
| March | 334 | 0.9794 | 322 | 1.005 | | 3.6% | 2.6% |
| April | 357.5 | 1.129 | 343.6 | 1.162 | | 3.9% | 2.9% |
| May | 449.1 | 0.9971 | 433.6 | 1.019 | | 3.5% | 2.2% |
| June | 549.8 | 1.747 | 530.2 | 1.798 | | 3.6% | 2.9% |
| July | 308 | 1.62 | 291.4 | 1.674 | | 5.4% | 3.3% |
| August | 253.1 | 2.392 | 237.8 | 2.499 | | 6.0% | 4.5% |
| September | 333.5 | 1.59 | 313.9 | 1.661 | | 5.9% | 4.5% |
| October | 427.4 | 1.134 | 412.7 | 1.156 | | 3.4% | 1.9% |
| November | 329.3 | 1.439 | 318.2 | 1.481 | | 3.4% | 2.9% |
| December | 308.7 | 1.143 | 299 | 1.173 | | 3.1% | 2.6% |
| | | | | | Average | 4.0% | 3.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.209 | 2.178 | 2.171 | 2.161 | | 1.7% | 0.8% |
| 3-day minimum | 2.817 | 2.008 | 2.755 | 1.956 | | 2.2% | 2.6% |
| 7-day minimum | 4.691 | 2.033 | 4.499 | 1.957 | | 4.1% | 3.7% |
| 30-day minimum | 30.61 | 1.118 | 28.05 | 1.097 | | 8.4% | 1.9% |
| 90-day minimum | 98.25 | 0.8236 | 90.66 | 0.8308 | | 7.7% | 0.9% |
| 1-day maximum | 7820 | 1.394 | 7732 | 1.399 | | 1.1% | 0.4% |
| 3-day maximum | 4733 | 1.194 | 4662 | 1.2 | | 1.5% | 0.5% |
| 7-day maximum | 3090 | 1.024 | 3043 | 1.032 | | 1.5% | 0.8% |
| 30-day maximum | 1375 | 0.884 | 1347 | 0.8973 | | 2.0% | 1.5% |
| 90-day maximum | 779.1 | 0.7937 | 758.3 | 0.8082 | | 2.7% | 1.8% |
| | | | | | Average | 3.3% | 1.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 157.6 | 0.2414 | 157.1 | 0.2393 | | 0.3% | 0.9% |
| Date of maximum | 187.7 | 0.251 | 187.7 | 0.251 | | 0.0% | 0.0% |
| | | | | | Average | 0.2% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 6.463 | 0.5394 | 6.788 | 0.4932 | | 5.0% | 8.6% |
| Low pulse duration | 13.49 | 0.6091 | 13.09 | 0.634 | | 3.0% | 4.1% |
| High pulse count | 2.675 | 0.7658 | 2.713 | 0.783 | | 1.4% | 2.2% |
| High pulse duration | 5.356 | 0.6773 | 5.182 | 0.6925 | | 3.2% | 2.2% |
| | | | | | Average | 3.2% | 4.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 190.4 | 0.9338 | 177.7 | 0.9608 | | 6.7% | 2.9% |
| Fall rate | -66.24 | -0.8401 | -66.92 | -0.8351 | | 1.0% | 0.6% |
| Number of reversals | 62.45 | 0.143 | 72.91 | 0.1604 | | 16.7% | 12.2% |
| | | | | | Average | 8.1% | 5.2% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.34 DHRAM results at Control Point CP08 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP08 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 125.3 | 1.414 | 124 | 1.425 | | 1.0% | 0.8% |
| February | 150.7 | 1.179 | 149.4 | 1.189 | | 0.9% | 0.8% |
| March | 147.1 | 1.043 | 145.7 | 1.049 | | 1.0% | 0.6% |
| April | 154.4 | 1.179 | 152.9 | 1.185 | | 1.0% | 0.5% |
| May | 196.4 | 1.05 | 194.3 | 1.057 | | 1.1% | 0.7% |
| June | 224.4 | 1.418 | 222.2 | 1.428 | | 1.0% | 0.7% |
| July | 116.1 | 1.735 | 114.5 | 1.748 | | 1.4% | 0.7% |
| August | 61.9 | 1.279 | 60.58 | 1.291 | | 2.1% | 0.9% |
| September | 112 | 1.629 | 109.5 | 1.647 | | 2.2% | 1.1% |
| October | 150.4 | 1.393 | 148.3 | 1.408 | | 1.4% | 1.1% |
| November | 141.1 | 1.47 | 139.8 | 1.481 | | 0.9% | 0.7% |
| December | 122.4 | 1.441 | 121.4 | 1.446 | | 0.8% | 0.3% |
| | | | | | Average | 1.2% | 0.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.708 | 1.002 | 2.714 | 1.002 | | 0.2% | 0.0% |
| 3-day minimum | 3.015 | 0.974 | 3.02 | 0.9737 | | 0.2% | 0.0% |
| 7-day minimum | 3.816 | 1.03 | 3.803 | 1.02 | | 0.3% | 1.0% |
| 30-day minimum | 12.56 | 0.8365 | 12.4 | 0.8265 | | 1.3% | 1.2% |
| 90-day minimum | 38.24 | 0.7582 | 37.49 | 0.7594 | | 2.0% | 0.2% |
| 1-day maximum | 3545 | 1.406 | 3519 | 1.405 | | 0.7% | 0.1% |
| 3-day maximum | 2090 | 1.048 | 2075 | 1.048 | | 0.7% | 0.0% |
| 7-day maximum | 1294 | 0.885 | 1286 | 0.8864 | | 0.6% | 0.2% |
| 30-day maximum | 563.9 | 0.7527 | 559.5 | 0.7569 | | 0.8% | 0.6% |
| 90-day maximum | 308.9 | 0.7148 | 306.1 | 0.7193 | | 0.9% | 0.6% |
| | | | | | Average | 0.8% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 78.81 | 0.2986 | 78.81 | 0.2986 | | 0.0% | 0.0% |
| Date of maximum | 187.7 | 0.2637 | 187.7 | 0.2637 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.5 | 0.5446 | 7.813 | 0.5072 | | 4.2% | 6.9% |
| Low pulse duration | 11.48 | 0.5492 | 11.12 | 0.5597 | | 3.1% | 1.9% |
| High pulse count | 2.75 | 0.8069 | 2.738 | 0.8048 | | 0.4% | 0.3% |
| High pulse duration | 5.452 | 0.6799 | 5.418 | 0.6933 | | 0.6% | 2.0% |
| | | | | | Average | 2.1% | 2.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 77.11 | 1.014 | 74.34 | 1.011 | | 3.6% | 0.3% |
| Fall rate | -29.96 | -0.8709 | -30.38 | -0.863 | | 1.4% | 0.9% |
| Number of reversals | 83.13 | 0.1457 | 90.21 | 0.1435 | | 8.5% | 1.5% |
| | | | | | Average | 4.5% | 0.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.35 DHRAM results at Control Point CP10 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP10 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 371.5 | 1.111 | 364.8 | 1.123 | | 1.8% | 1.1% |
| February | 399 | 0.922 | 392.8 | 0.9306 | | 1.6% | 0.9% |
| March | 339.4 | 0.7574 | 333.2 | 0.7619 | | 1.8% | 0.6% |
| April | 410.3 | 0.9457 | 403.3 | 0.9511 | | 1.7% | 0.6% |
| May | 498.4 | 0.9128 | 489 | 0.9206 | | 1.9% | 0.9% |
| June | 536.5 | 1.296 | 525.4 | 1.313 | | 2.1% | 1.3% |
| July | 316.7 | 1.229 | 308.1 | 1.243 | | 2.7% | 1.1% |
| August | 199.2 | 0.6832 | 192.6 | 0.6842 | | 3.3% | 0.1% |
| September | 299.6 | 0.9683 | 291.3 | 0.9778 | | 2.8% | 1.0% |
| October | 443.3 | 1.387 | 435.7 | 1.403 | | 1.7% | 1.2% |
| November | 419.9 | 1.279 | 414.1 | 1.29 | | 1.4% | 0.9% |
| December | 358.2 | 0.9849 | 352.6 | 0.9923 | | 1.6% | 0.8% |
| | | | | | Average | 2.0% | 0.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 1.696 | 2.088 | 1.441 | 2.471 | | 15.0% | 18.3% |
| 3-day minimum | 2.135 | 2.004 | 2.027 | 2.128 | | 5.1% | 6.2% |
| 7-day minimum | 3.689 | 1.877 | 3.763 | 1.876 | | 2.0% | 0.1% |
| 30-day minimum | 32.75 | 0.9026 | 33.15 | 0.8768 | | 1.2% | 2.9% |
| 90-day minimum | 129.5 | 0.5554 | 126.3 | 0.5521 | | 2.5% | 0.6% |
| 1-day maximum | 7061 | 1.104 | 6993 | 1.112 | | 1.0% | 0.7% |
| 3-day maximum | 4707 | 0.8669 | 4650 | 0.8749 | | 1.2% | 0.9% |
| 7-day maximum | 3181 | 0.7928 | 3146 | 0.7991 | | 1.1% | 0.8% |
| 30-day maximum | 1360 | 0.7428 | 1342 | 0.7495 | | 1.3% | 0.9% |
| 90-day maximum | 776.3 | 0.6635 | 764 | 0.6688 | | 1.6% | 0.8% |
| | | | | | Average | 3.2% | 3.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 166.4 | 0.2556 | 165.1 | 0.2493 | | 0.8% | 2.5% |
| Date of maximum | 181.2 | 0.2372 | 176.6 | 0.2372 | | 2.5% | 0.0% |
| | | | | | Average | 1.7% | 1.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 9.113 | 0.4966 | 8.95 | 0.4581 | | 1.8% | 7.8% |
| Low pulse duration | 9.845 | 0.331 | 9.933 | 0.3472 | | 0.9% | 4.9% |
| High pulse count | 4.913 | 0.6631 | 4.913 | 0.6631 | | 0.0% | 0.0% |
| High pulse duration | 3.909 | 0.4972 | 3.866 | 0.5258 | | 1.1% | 5.8% |
| | | | | | Average | 0.9% | 4.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 330.1 | 0.6384 | 299.2 | 0.657 | | 9.4% | 2.9% |
| Fall rate | -79.4 | -0.5742 | -79.16 | -0.5869 | | 0.3% | 2.2% |
| Number of reversals | 66.4 | 0.1356 | 76.24 | 0.1251 | | 14.8% | 7.7% |
| | | | | | Average | 8.2% | 4.3% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.36 DHRAM results at Control Point CP11 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | CP11 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 91.02 | 1.737 | 90.68 | 1.739 | | 0.4% | 0.1% |
| February | 105.5 | 1.552 | 105.2 | 1.553 | | 0.3% | 0.1% |
| March | 72.75 | 1.757 | 72.26 | 1.755 | | 0.7% | 0.1% |
| April | 147.5 | 1.686 | 146.7 | 1.685 | | 0.5% | 0.1% |
| May | 187.4 | 1.605 | 186.3 | 1.609 | | 0.6% | 0.2% |
| June | 179.3 | 1.939 | 178.4 | 1.944 | | 0.5% | 0.3% |
| July | 75.47 | 3.604 | 75 | 3.621 | | 0.6% | 0.5% |
| August | 29.32 | 3.08 | 29.02 | 3.087 | | 1.0% | 0.2% |
| September | 73.69 | 1.696 | 72.82 | 1.7 | | 1.2% | 0.2% |
| October | 164.5 | 2.169 | 163.4 | 2.175 | | 0.7% | 0.3% |
| November | 112.8 | 2.147 | 112 | 2.153 | | 0.7% | 0.3% |
| December | 96.09 | 2.03 | 95.51 | 2.026 | | 0.6% | 0.2% |
| | | | | | Average | 0.6% | 0.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0.000 | 0.000 | 0.00 | 0.00 | | 0.0% | 0.0% |
| 3-day minimum | 0.000 | 0.000 | 0.00 | 0.00 | | 0.0% | 0.0% |
| 7-day minimum | 0.001 | 8.944 | 0.00 | 0.00 | | 100.0% | 100.0% |
| 30-day minimum | 0.580 | 2.034 | 0.56 | 2.06 | | 2.9% | 1.2% |
| 90-day minimum | 6.944 | 1.708 | 6.84 | 1.71 | | 1.5% | 0.2% |
| 1-day maximum | 5305 | 1.224 | 5286 | 1.23 | | 0.4% | 0.2% |
| 3-day maximum | 3202 | 0.939 | 3185 | 0.94 | | 0.5% | 0.3% |
| 7-day maximum | 1923 | 0.859 | 1913 | 0.86 | | 0.5% | 0.3% |
| 30-day maximum | 653.3 | 0.814 | 650 | 0.82 | | 0.5% | 0.3% |
| 90-day maximum | 290.6 | 0.792 | 289 | 0.79 | | 0.6% | 0.3% |
| | | | | | Average | 10.7% | 10.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 67.2 | 0.1697 | 65.38 | 0.1687 | | 2.7% | 0.6% |
| Date of maximum | 183.5 | 0.2629 | 183.5 | 0.2629 | | 0.0% | 0.0% |
| | | | | | Average | 1.4% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 6.738 | 0.4095 | 6.963 | 0.4072 | | 3.3% | 0.6% |
| Low pulse duration | 12.14 | 0.6276 | 12.16 | 0.6245 | | 0.2% | 0.5% |
| High pulse count | 4.138 | 0.7474 | 4.125 | 0.7503 | | 0.3% | 0.4% |
| High pulse duration | 3.055 | 0.3647 | 3.064 | 0.3714 | | 0.3% | 1.8% |
| | | | | | Average | 1.0% | 0.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 267.5 | 0.9594 | 266.3 | 0.9694 | | 0.4% | 1.0% |
| Fall rate | -58.79 | -0.8423 | -58.92 | -0.8467 | | 0.2% | 0.5% |
| Number of reversals | 59.66 | 0.2018 | 59.9 | 0.204 | | 0.4% | 1.1% |
| | | | | | Average | 0.4% | 0.9% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 0 |
| Classification | | 1 |
| note: | Un-impacted condition | |

Table 9.36 (Continued)

| Control Point: | CP11 | | Period: | 1934-2013 | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 91.02 | 1.737 | 90.12 | 1.742 | | 1.0% | 0.3% |
| February | 105.5 | 1.552 | 104.9 | 1.559 | | 0.6% | 0.5% |
| March | 72.75 | 1.757 | 72.14 | 1.765 | | 0.8% | 0.5% |
| April | 147.5 | 1.686 | 146.7 | 1.688 | | 0.5% | 0.1% |
| May | 187.4 | 1.605 | 186.3 | 1.611 | | 0.6% | 0.4% |
| June | 179.3 | 1.939 | 178.4 | 1.946 | | 0.5% | 0.4% |
| July | 75.47 | 3.604 | 74.97 | 3.625 | | 0.7% | 0.6% |
| August | 29.32 | 3.08 | 28.82 | 3.089 | | 1.7% | 0.3% |
| September | 73.69 | 1.696 | 72.56 | 1.705 | | 1.5% | 0.5% |
| October | 164.5 | 2.169 | 163.6 | 2.176 | | 0.5% | 0.3% |
| November | 112.8 | 2.147 | 112.1 | 2.156 | | 0.6% | 0.4% |
| December | 96.09 | 2.03 | 95.56 | 2.036 | | 0.6% | 0.3% |
| | | | | | Average | 0.8% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0 | 0 | 0 | 0 | | 0.0% | 0.0% |
| 3-day minimum | 0 | 0 | 0 | 0 | | 0.0% | 0.0% |
| 7-day minimum | 0.0008929 | 8.944 | 0.0008929 | 8.944 | | 0.0% | 0.0% |
| 30-day minimum | 0.5803 | 2.034 | 0.5659 | 2.034 | | 2.5% | 0.0% |
| 90-day minimum | 6.944 | 1.708 | 6.821 | 1.723 | | 1.8% | 0.9% |
| 1-day maximum | 5305 | 1.224 | 5280 | 1.23 | | 0.5% | 0.5% |
| 3-day maximum | 3202 | 0.9394 | 3184 | 0.9441 | | 0.6% | 0.5% |
| 7-day maximum | 1923 | 0.8586 | 1914 | 0.8622 | | 0.5% | 0.4% |
| 30-day maximum | 653.3 | 0.814 | 650.2 | 0.8178 | | 0.5% | 0.5% |
| 90-day maximum | 290.6 | 0.7923 | 289 | 0.7957 | | 0.6% | 0.4% |
| | | | | | Average | 0.7% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 67.2 | 0.1697 | 68.3 | 0.1692 | | 1.6% | 0.3% |
| Date of maximum | 183.5 | 0.2629 | 184.1 | 0.2619 | | 0.3% | 0.4% |
| | | | | | Average | 1.0% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 6.738 | 0.4095 | 6.663 | 0.4045 | | 1.1% | 1.2% |
| Low pulse duration | 12.14 | 0.6276 | 12.16 | 0.62 | | 0.2% | 1.2% |
| High pulse count | 4.138 | 0.7474 | 4.113 | 0.7502 | | 0.6% | 0.4% |
| High pulse duration | 3.055 | 0.3647 | 3.061 | 0.3827 | | 0.2% | 4.9% |
| | | | | | Average | 0.5% | 1.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 267.5 | 0.9594 | 266.7 | 0.9582 | | 0.3% | 0.1% |
| Fall rate | -58.79 | -0.8423 | -58.72 | -0.8466 | | 0.1% | 0.5% |
| Number of reversals | 59.66 | 0.2018 | 59.86 | 0.2008 | | 0.3% | 0.5% |
| | | | | | Average | 0.3% | 0.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.37 DHRAM results at Control Point C3824 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | C3824 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1229 | 0.9786 | 1073 | 0.9733 | | 12.7% | 0.5% |
| February | 1317 | 0.8344 | 1171 | 0.8706 | | 11.1% | 4.3% |
| March | 1165 | 0.6849 | 1028 | 0.8398 | | 11.8% | 22.6% |
| April | 1333 | 0.8284 | 1107 | 0.7941 | | 17.0% | 4.1% |
| May | 1727 | 0.8953 | 1518 | 0.8918 | | 12.1% | 0.4% |
| June | 1764 | 1.242 | 1517 | 1.09 | | 14.0% | 12.2% |
| July | 1148 | 1.321 | 1079 | 1.37 | | 6.0% | 3.7% |
| August | 722.1 | 0.9311 | 632.3 | 1.022 | | 12.4% | 9.8% |
| September | 1100 | 0.9068 | 915.6 | 0.8789 | | 16.8% | 3.1% |
| October | 1505 | 1.216 | 1273 | 1.198 | | 15.4% | 1.5% |
| November | 1378 | 1.11 | 1246 | 1.067 | | 9.6% | 3.9% |
| December | 1209 | 0.9573 | 1103 | 0.8722 | | 8.8% | 8.9% |
| | | | | | Average | 12.3% | 6.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 31.59 | 1.447 | 48.26 | 0.7568 | | 52.8% | 47.7% |
| 3-day minimum | 35.08 | 1.37 | 54.27 | 0.8099 | | 54.7% | 40.9% |
| 7-day minimum | 46.5 | 1.179 | 66.24 | 0.7629 | | 42.5% | 35.3% |
| 30-day minimum | 192.7 | 0.8935 | 224.4 | 0.754 | | 16.5% | 15.6% |
| 90-day minimum | 463.8 | 0.6091 | 427.3 | 0.4976 | | 7.9% | 18.3% |
| 1-day maximum | 12870 | 0.8557 | 10070 | 0.936 | | 21.8% | 9.4% |
| 3-day maximum | 11220 | 0.8109 | 8370 | 0.8594 | | 25.4% | 6.0% |
| 7-day maximum | 8846 | 0.776 | 6421 | 0.7775 | | 27.4% | 0.2% |
| 30-day maximum | 4280 | 0.7091 | 3533 | 0.7049 | | 17.5% | 0.6% |
| 90-day maximum | 2510 | 0.6279 | 2195 | 0.6887 | | 12.5% | 9.7% |
| | | | | | Average | 27.9% | 18.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 178.3 | 0.2386 | 194.3 | 0.2361 | | 9.0% | 1.0% |
| Date of maximum | 179.6 | 0.2524 | 171.3 | 0.2663 | | 4.6% | 5.5% |
| | | | | | Average | 6.8% | 3.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.638 | 0.4979 | 7.838 | 0.3102 | | 39.0% | 37.7% |
| Low pulse duration | 16.33 | 0.8308 | 11.72 | 0.8984 | | 28.2% | 8.1% |
| High pulse count | 3.9 | 0.7896 | 6.475 | 0.7813 | | 66.0% | 1.1% |
| High pulse duration | 7.179 | 0.5002 | 4.889 | 0.4371 | | 31.9% | 12.6% |
| | | | | | Average | 41.3% | 14.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 415.3 | 0.6525 | 339.8 | 0.6411 | | 18.2% | 1.7% |
| Fall rate | -146 | -0.5489 | -211 | -0.6745 | | 44.5% | 22.9% |
| Number of reversals | 52.79 | 0.1697 | 86.84 | 0.2087 | | 64.5% | 23.0% |
| | | | | | Average | 42.4% | 15.9% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 1 |
| Classification | | 2 |
| note: | Low risk of impact | |

## Table 9.37 (Continued)

| Control Point: | C3824 | Period: | 1934-2013 | | | |
|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | |
| January | 1229 | 0.9786 | 1087 | 0.9795 | 11.6% | 0.1% |
| February | 1317 | 0.8344 | 1180 | 0.878 | 10.4% | 5.2% |
| March | 1165 | 0.6849 | 1062 | 0.8678 | 8.8% | 26.7% |
| April | 1333 | 0.8284 | 1162 | 0.8108 | 12.8% | 2.1% |
| May | 1727 | 0.8953 | 1517 | 0.9053 | 12.2% | 1.1% |
| June | 1764 | 1.242 | 1512 | 1.108 | 14.3% | 10.8% |
| July | 1148 | 1.321 | 1072 | 1.389 | 6.6% | 5.1% |
| August | 722.1 | 0.9311 | 642.4 | 1.079 | 11.0% | 15.9% |
| September | 1100 | 0.9068 | 923.6 | 0.9073 | 16.0% | 0.1% |
| October | 1505 | 1.216 | 1267 | 1.223 | 15.8% | 0.6% |
| November | 1378 | 1.11 | 1236 | 1.105 | 10.3% | 0.5% |
| December | 1209 | 0.9573 | 1084 | 0.93 | 10.3% | 2.9% |
| | | | | Average | 11.7% | 5.9% |
| | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | |
| 1-day minimum | 31.59 | 1.447 | 11.16 | 1.433 | 64.7% | 1.0% |
| 3-day minimum | 35.08 | 1.37 | 18.5 | 1.323 | 47.3% | 3.4% |
| 7-day minimum | 46.5 | 1.179 | 36.04 | 1.198 | 22.5% | 1.6% |
| 30-day minimum | 192.7 | 0.8935 | 166.4 | 0.7879 | 13.6% | 11.8% |
| 90-day minimum | 463.8 | 0.6091 | 390.4 | 0.5819 | 15.8% | 4.5% |
| 1-day maximum | 12870 | 0.8557 | 11250 | 0.7975 | 12.6% | 6.8% |
| 3-day maximum | 11220 | 0.8109 | 9213 | 0.7564 | 17.9% | 6.7% |
| 7-day maximum | 8846 | 0.776 | 6975 | 0.6966 | 21.2% | 10.2% |
| 30-day maximum | 4280 | 0.7091 | 3642 | 0.6717 | 14.9% | 5.3% |
| 90-day maximum | 2510 | 0.6279 | 2252 | 0.6772 | 10.3% | 7.9% |
| | | | | Average | 24.1% | 5.9% |
| | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | |
| Date of minimum | 178.3 | 0.2386 | 169.6 | 0.2631 | 4.9% | 10.3% |
| Date of maximum | 179.6 | 0.2524 | 167.4 | 0.2545 | 6.8% | 0.8% |
| | | | | Average | 5.8% | 5.6% |
| | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | |
| Low pulse count | 5.638 | 0.4979 | 20.11 | 0.2543 | 256.7% | 48.9% |
| Low pulse duration | 16.33 | 0.8308 | 5.457 | 1.187 | 66.6% | 42.9% |
| High pulse count | 3.9 | 0.7896 | 9.825 | 0.7155 | 151.9% | 9.4% |
| High pulse duration | 7.179 | 0.5002 | 3.671 | 0.4249 | 48.9% | 15.1% |
| | | | | Average | 131.0% | 29.1% |
| | | | | Score | 3 | 0 |
| Parameter Group #5 | | | | | | |
| Rise rate | 415.3 | 0.6525 | 525.8 | 0.4602 | 26.6% | 29.5% |
| Fall rate | -146 | -0.5489 | -431.5 | -0.5083 | 195.5% | 7.4% |
| Number of reversals | 52.79 | 0.1697 | 146.2 | 0.1576 | 176.9% | 7.1% |
| | | | | Average | 133.0% | 14.7% |
| | | | | Score | 3 | 0 |

| | |
|---|---|
| Total Point | 6 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 9.38 DHRAM results at Control Point CP13 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | CP13 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 112.4 | 1.983 | 111.6 | 1.985 | | 0.7% | 0.1% |
| February | 111.1 | 1.914 | 110.3 | 1.921 | | 0.7% | 0.4% |
| March | 63.93 | 2.042 | 63.51 | 2.049 | | 0.7% | 0.3% |
| April | 138.7 | 1.846 | 137.8 | 1.847 | | 0.6% | 0.1% |
| May | 201.3 | 1.719 | 200.1 | 1.72 | | 0.6% | 0.1% |
| June | 206.7 | 2.134 | 205.8 | 2.138 | | 0.4% | 0.2% |
| July | 77.17 | 3.51 | 76.81 | 3.521 | | 0.5% | 0.3% |
| August | 33.29 | 3.22 | 33.11 | 3.224 | | 0.5% | 0.1% |
| September | 192.6 | 2.93 | 191.2 | 2.936 | | 0.7% | 0.2% |
| October | 221.7 | 2.395 | 220.4 | 2.401 | | 0.6% | 0.3% |
| November | 121.6 | 2.479 | 120.9 | 2.488 | | 0.6% | 0.4% |
| December | 99.78 | 2.317 | 99.03 | 2.323 | | 0.8% | 0.3% |
| | | | | | Average | 0.6% | 0.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0.0375 | 3.534 | 0.04 | 3.53 | | 0.0% | 0.0% |
| 3-day minimum | 0.06042 | 2.531 | 0.06 | 2.53 | | 0.0% | 0.0% |
| 7-day minimum | 0.1286 | 2.104 | 0.13 | 2.12 | | 1.4% | 0.6% |
| 30-day minimum | 1.437 | 1.353 | 1.43 | 1.35 | | 0.8% | 0.1% |
| 90-day minimum | 9.875 | 1.103 | 9.80 | 1.10 | | 0.7% | 0.2% |
| 1-day maximum | 5100 | 1.452 | 5080 | 1.45 | | 0.4% | 0.0% |
| 3-day maximum | 3436 | 1.227 | 3416 | 1.23 | | 0.6% | 0.0% |
| 7-day maximum | 2312 | 1.14 | 2300 | 1.14 | | 0.5% | 0.1% |
| 30-day maximum | 823.1 | 1.016 | 819 | 1.02 | | 0.5% | 0.2% |
| 90-day maximum | 373.1 | 0.9611 | 371 | 0.96 | | 0.5% | 0.2% |
| | | | | | Average | 0.5% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 109.7 | 0.2301 | 108.9 | 0.2312 | | 0.7% | 0.5% |
| Date of maximum | 185.4 | 0.264 | 185.4 | 0.2639 | | 0.0% | 0.0% |
| | | | | | Average | 0.4% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8.588 | 0.3297 | 8.6 | 0.3313 | | 0.1% | 0.5% |
| Low pulse duration | 10.3 | 0.3899 | 10.31 | 0.3874 | | 0.1% | 0.6% |
| High pulse count | 2.638 | 0.9917 | 2.625 | 0.9948 | | 0.5% | 0.3% |
| High pulse duration | 4.849 | 0.4993 | 4.841 | 0.5003 | | 0.2% | 0.2% |
| | | | | | Average | 0.2% | 0.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 153.7 | 1.123 | 153.5 | 1.122 | | 0.1% | 0.1% |
| Fall rate | -46.96 | -1.053 | -46.84 | -1.054 | | 0.3% | 0.1% |
| Number of reversals | 59.95 | 0.1762 | 60.2 | 0.1778 | | 0.4% | 0.9% |
| | | | | | Average | 0.3% | 0.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

## Table 9.38 (Continued)

Control Point: CP13 Period: 1934-2013

| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 112.4 | 1.983 | 111.6 | 1.983 | | 0.7% | 0.0% |
| February | 111.1 | 1.914 | 110.3 | 1.919 | | 0.7% | 0.3% |
| March | 63.93 | 2.042 | 63.51 | 2.049 | | 0.7% | 0.3% |
| April | 138.7 | 1.846 | 137.8 | 1.847 | | 0.6% | 0.1% |
| May | 201.3 | 1.719 | 200 | 1.72 | | 0.6% | 0.1% |
| June | 206.7 | 2.134 | 205.8 | 2.137 | | 0.4% | 0.1% |
| July | 77.17 | 3.51 | 76.79 | 3.518 | | 0.5% | 0.2% |
| August | 33.29 | 3.22 | 33.1 | 3.222 | | 0.6% | 0.1% |
| September | 192.6 | 2.93 | 191.3 | 2.935 | | 0.7% | 0.2% |
| October | 221.7 | 2.395 | 220.4 | 2.4 | | 0.6% | 0.2% |
| November | 121.6 | 2.479 | 120.9 | 2.487 | | 0.6% | 0.3% |
| December | 99.78 | 2.317 | 99.1 | 2.322 | | 0.7% | 0.2% |
| | | | | | Average | 0.6% | 0.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 0.0375 | 3.534 | 0.0375 | 3.534 | | 0.0% | 0.0% |
| 3-day minimum | 0.06042 | 2.531 | 0.06042 | 2.531 | | 0.0% | 0.0% |
| 7-day minimum | 0.1286 | 2.104 | 0.1286 | 2.104 | | 0.0% | 0.0% |
| 30-day minimum | 1.437 | 1.353 | 1.433 | 1.352 | | 0.3% | 0.1% |
| 90-day minimum | 9.875 | 1.103 | 9.819 | 1.101 | | 0.6% | 0.2% |
| 1-day maximum | 5100 | 1.452 | 5078 | 1.453 | | 0.4% | 0.1% |
| 3-day maximum | 3436 | 1.227 | 3414 | 1.228 | | 0.6% | 0.1% |
| 7-day maximum | 2312 | 1.14 | 2299 | 1.142 | | 0.6% | 0.2% |
| 30-day maximum | 823.1 | 1.016 | 818.7 | 1.019 | | 0.5% | 0.3% |
| 90-day maximum | 373.1 | 0.9611 | 371.1 | 0.9632 | | 0.5% | 0.2% |
| | | | | | Average | 0.4% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 109.7 | 0.2301 | 109.7 | 0.2301 | | 0.0% | 0.0% |
| Date of maximum | 185.4 | 0.264 | 185.4 | 0.2639 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 8.588 | 0.3297 | 8.6 | 0.3292 | | 0.1% | 0.2% |
| Low pulse duration | 10.3 | 0.3899 | 10.29 | 0.3908 | | 0.1% | 0.2% |
| High pulse count | 2.638 | 0.9917 | 2.65 | 0.9868 | | 0.5% | 0.5% |
| High pulse duration | 4.849 | 0.4993 | 4.815 | 0.5057 | | 0.7% | 1.3% |
| | | | | | Average | 0.3% | 0.5% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 153.7 | 1.123 | 153.7 | 1.128 | | 0.0% | 0.4% |
| Fall rate | -46.96 | -1.053 | -46.84 | -1.055 | | 0.3% | 0.2% |
| Number of reversals | 59.95 | 0.1762 | 59.96 | 0.177 | | 0.0% | 0.5% |
| | | | | | Average | 0.1% | 0.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.39 DHRAM results at Control Point CP14 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | CP14 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1546 | 1.107 | 1425 | 1.08 | | 7.8% | 2.4% |
| February | 1665 | 1.003 | 1549 | 1 | | 7.0% | 0.3% |
| March | 1387 | 0.7822 | 1244 | 0.8533 | | 10.3% | 9.1% |
| April | 1681 | 1.048 | 1466 | 1.039 | | 12.8% | 0.9% |
| May | 2449 | 1.088 | 2197 | 1.109 | | 10.3% | 1.9% |
| June | 2429 | 1.411 | 2194 | 1.328 | | 9.7% | 5.9% |
| July | 1487 | 1.669 | 1433 | 1.641 | | 3.6% | 1.7% |
| August | 803.3 | 1.044 | 742 | 1.019 | | 7.6% | 2.4% |
| September | 1551 | 1.242 | 1343 | 1.281 | | 13.4% | 3.1% |
| October | 2085 | 1.479 | 1902 | 1.45 | | 8.8% | 2.0% |
| November | 1932 | 1.333 | 1828 | 1.291 | | 5.4% | 3.2% |
| December | 1516 | 1.095 | 1481 | 0.9808 | | 2.3% | 10.4% |
| | | | | | Average | 8.3% | 3.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 48.59 | 1.383 | 48.69 | 0.87 | | 0.2% | 37.4% |
| 3-day minimum | 55.96 | 1.342 | 56.87 | 1.07 | | 1.6% | 20.4% |
| 7-day minimum | 73.24 | 1.329 | 75.03 | 1.16 | | 2.4% | 12.4% |
| 30-day minimum | 214.9 | 1.023 | 251.50 | 0.85 | | 17.0% | 17.2% |
| 90-day minimum | 494.5 | 0.716 | 502.70 | 0.58 | | 1.7% | 19.1% |
| 1-day maximum | 16910 | 0.9098 | 14400 | 0.96 | | 14.8% | 5.7% |
| 3-day maximum | 15120 | 0.8723 | 12710 | 0.91 | | 15.9% | 4.6% |
| 7-day maximum | 12880 | 0.8619 | 10860 | 0.91 | | 15.7% | 5.9% |
| 30-day maximum | 6357 | 0.7906 | 5624 | 0.82 | | 11.5% | 3.4% |
| 90-day maximum | 3578 | 0.7132 | 3262 | 0.76 | | 8.8% | 6.5% |
| | | | | | Average | 9.0% | 13.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 205.3 | 0.2309 | 193.5 | 0.2481 | | 5.7% | 7.4% |
| Date of maximum | 188.6 | 0.2587 | 180.3 | 0.2632 | | 4.4% | 1.7% |
| | | | | | Average | 5.1% | 4.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.6 | 0.6251 | 6.65 | 0.4207 | | 44.6% | 32.7% |
| Low pulse duration | 21.77 | 0.9537 | 13.9 | 0.9574 | | 36.2% | 0.4% |
| High pulse count | 2.763 | 0.7965 | 3.863 | 0.8765 | | 39.8% | 10.0% |
| High pulse duration | 9.087 | 0.5568 | 8.2 | 0.7889 | | 9.8% | 41.7% |
| | | | | | Average | 32.6% | 21.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 401.5 | 0.6933 | 339.2 | 0.6779 | | 15.5% | 2.2% |
| Fall rate | -176.1 | -0.6437 | -212.7 | -0.6605 | | 20.8% | 2.6% |
| Number of reversals | 51.25 | 0.1504 | 86.23 | 0.1985 | | 68.3% | 32.0% |
| | | | | | Average | 34.9% | 12.3% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.39 (Continued)

| Control Point: | CP14 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1546 | 1.107 | 1416 | 1.123 | | 8.4% | 1.4% |
| February | 1665 | 1.003 | 1545 | 1.039 | | 7.2% | 3.6% |
| March | 1387 | 0.7822 | 1289 | 0.8951 | | 7.1% | 14.4% |
| April | 1681 | 1.048 | 1528 | 1.043 | | 9.1% | 0.5% |
| May | 2449 | 1.088 | 2259 | 1.104 | | 7.8% | 1.5% |
| June | 2429 | 1.411 | 2204 | 1.34 | | 9.3% | 5.0% |
| July | 1487 | 1.669 | 1424 | 1.703 | | 4.2% | 2.0% |
| August | 803.3 | 1.044 | 732.1 | 1.173 | | 8.9% | 12.4% |
| September | 1551 | 1.242 | 1388 | 1.324 | | 10.5% | 6.6% |
| October | 2085 | 1.479 | 1873 | 1.51 | | 10.2% | 2.1% |
| November | 1932 | 1.333 | 1798 | 1.345 | | 6.9% | 0.9% |
| December | 1516 | 1.095 | 1415 | 1.07 | | 6.7% | 2.3% |
| | | | | | Average | 8.0% | 4.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 48.59 | 1.383 | 16.65 | 1.248 | | 65.7% | 9.8% |
| 3-day minimum | 55.96 | 1.342 | 27.3 | 1.186 | | 51.2% | 11.6% |
| 7-day minimum | 73.24 | 1.329 | 59.82 | 1.238 | | 18.3% | 6.8% |
| 30-day minimum | 214.9 | 1.023 | 189 | 1.008 | | 12.1% | 1.5% |
| 90-day minimum | 494.5 | 0.716 | 432.9 | 0.7229 | | 12.5% | 1.0% |
| 1-day maximum | 16910 | 0.9098 | 15490 | 0.9263 | | 8.4% | 1.8% |
| 3-day maximum | 15120 | 0.8723 | 13510 | 0.8708 | | 10.6% | 0.2% |
| 7-day maximum | 12880 | 0.8619 | 11420 | 0.8655 | | 11.3% | 0.4% |
| 30-day maximum | 6357 | 0.7906 | 5806 | 0.7836 | | 8.7% | 0.9% |
| 90-day maximum | 3578 | 0.7132 | 3347 | 0.7429 | | 6.5% | 4.2% |
| | | | | | Average | 20.5% | 3.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 205.3 | 0.2309 | 174.7 | 0.2751 | | 14.9% | 19.1% |
| Date of maximum | 188.6 | 0.2587 | 180.2 | 0.2563 | | 4.5% | 0.9% |
| | | | | | Average | 9.7% | 10.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.6 | 0.6251 | 13.04 | 0.4184 | | 183.5% | 33.1% |
| Low pulse duration | 21.77 | 0.9537 | 9.382 | 1.33 | | 56.9% | 39.5% |
| High pulse count | 2.763 | 0.7965 | 4.063 | 0.8312 | | 47.1% | 4.4% |
| High pulse duration | 9.087 | 0.5568 | 8.045 | 0.773 | | 11.5% | 38.8% |
| | | | | | Average | 74.7% | 28.9% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 401.5 | 0.6933 | 466.8 | 0.5262 | | 16.3% | 24.1% |
| Fall rate | -176.1 | -0.6437 | -336.4 | -0.5148 | | 91.0% | 20.0% |
| Number of reversals | 51.25 | 0.1504 | 128.2 | 0.1629 | | 150.1% | 8.3% |
| | | | | | Average | 85.8% | 17.5% |
| | | | | | Score | 2 | 0 |

| | |
|---|---|
| Total Point | 5 |
| Classification | 3 |
| note: | Moderate risk of impact |

Table 9.40 DHRAM results at Control Point CP15 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP15 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 1599 | 1.104 | 1443 | 1.147 | | 9.8% | 3.9% |
| February | 1703 | 1.001 | 1568 | 1.048 | | 7.9% | 4.7% |
| March | 1445 | 0.7707 | 1324 | 0.8797 | | 8.4% | 14.1% |
| April | 1742 | 1.006 | 1570 | 1.015 | | 9.9% | 0.9% |
| May | 2516 | 1.059 | 2297 | 1.088 | | 8.7% | 2.7% |
| June | 2544 | 1.428 | 2292 | 1.386 | | 9.9% | 2.9% |
| July | 1575 | 1.616 | 1479 | 1.684 | | 6.1% | 4.2% |
| August | 855 | 1.033 | 754.3 | 1.203 | | 11.8% | 16.5% |
| September | 1585 | 1.216 | 1398 | 1.311 | | 11.8% | 7.8% |
| October | 2124 | 1.417 | 1900 | 1.461 | | 10.5% | 3.1% |
| November | 1989 | 1.305 | 1838 | 1.333 | | 7.6% | 2.1% |
| December | 1565 | 1.067 | 1446 | 1.065 | | 7.6% | 0.2% |
| | | | | | Average | 9.2% | 5.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 59.18 | 1.461 | 12.03 | 1.246 | | 79.7% | 14.7% |
| 3-day minimum | 67.62 | 1.421 | 19.01 | 1.132 | | 71.9% | 20.3% |
| 7-day minimum | 86 | 1.378 | 55.46 | 1.263 | | 35.5% | 8.3% |
| 30-day minimum | 238.1 | 0.9643 | 194.4 | 0.9696 | | 18.4% | 0.5% |
| 90-day minimum | 535.8 | 0.6979 | 451.4 | 0.7204 | | 15.8% | 3.2% |
| 1-day maximum | 15310 | 0.8621 | 14060 | 0.8467 | | 8.2% | 1.8% |
| 3-day maximum | 14200 | 0.8593 | 12910 | 0.8446 | | 9.1% | 1.7% |
| 7-day maximum | 12460 | 0.8599 | 11190 | 0.8541 | | 10.2% | 0.7% |
| 30-day maximum | 6431 | 0.8038 | 5898 | 0.7999 | | 8.3% | 0.5% |
| 90-day maximum | 3657 | 0.7115 | 3413 | 0.7464 | | 6.7% | 4.9% |
| | | | | | Average | 26.4% | 5.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 197.3 | 0.2327 | 177.4 | 0.2783 | | 10.1% | 19.6% |
| Date of maximum | 187.8 | 0.2567 | 182.7 | 0.2567 | | 2.7% | 0.0% |
| | | | | | Average | 6.4% | 9.8% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.025 | 0.6041 | 15.03 | 0.3324 | | 199.1% | 45.0% |
| Low pulse duration | 20.01 | 1.01 | 6.91 | 0.9899 | | 65.5% | 2.0% |
| High pulse count | 2.75 | 0.7923 | 4.313 | 0.8247 | | 56.8% | 4.1% |
| High pulse duration | 9.291 | 0.5614 | 7.628 | 0.8483 | | 17.9% | 51.1% |
| | | | | | Average | 84.8% | 25.5% |
| | | | | | Score | 2 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 373.8 | 0.6418 | 467.6 | 0.4761 | | 25.1% | 25.8% |
| Fall rate | -168.3 | -0.6072 | -326.5 | -0.4774 | | 94.0% | 21.4% |
| Number of reversals | 53.58 | 0.1281 | 118.2 | 0.1346 | | 120.6% | 5.1% |
| | | | | | Average | 79.9% | 17.4% |
| | | | | | Score | 1 | 0 |

| | | |
|---|---|---|
| Total Point | | 3 |
| Classification | | 2 |
| note: | Low risk of impact | |

Table 9.41 DHRAM results at Control Point P38241 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | P3824 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 79.87 | 1.334 | 79.87 | 1.334 | | 0.0% | 0.0% |
| February | 88.76 | 1.141 | 88.64 | 1.135 | | 0.1% | 0.5% |
| March | 89.55 | 1.008 | 89.33 | 1.004 | | 0.2% | 0.4% |
| April | 100.4 | 1.12 | 100.3 | 1.118 | | 0.1% | 0.2% |
| May | 130.9 | 0.9941 | 130.7 | 0.9932 | | 0.2% | 0.1% |
| June | 164.2 | 1.789 | 163.8 | 1.783 | | 0.2% | 0.3% |
| July | 119.1 | 2.09 | 118.8 | 2.085 | | 0.3% | 0.2% |
| August | 106.1 | 2.402 | 105.9 | 2.403 | | 0.2% | 0.0% |
| September | 98.33 | 1.622 | 98.2 | 1.616 | | 0.1% | 0.4% |
| October | 124.6 | 1.302 | 124.3 | 1.295 | | 0.2% | 0.5% |
| November | 94.91 | 1.238 | 94.79 | 1.238 | | 0.1% | 0.0% |
| December | 77.88 | 1.141 | 77.84 | 1.141 | | 0.1% | 0.0% |
| | | | | | Average | 0.2% | 0.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 3.278 | 1.322 | 3.28 | 1.32 | | 0.0% | 0.0% |
| 3-day minimum | 3.51 | 1.301 | 3.51 | 1.30 | | 0.0% | 0.0% |
| 7-day minimum | 4.29 | 1.243 | 4.29 | 1.24 | | 0.0% | 0.0% |
| 30-day minimum | 11.67 | 0.9616 | 11.67 | 0.96 | | 0.0% | 0.0% |
| 90-day minimum | 27.76 | 0.9195 | 27.76 | 0.92 | | 0.0% | 0.0% |
| 1-day maximum | 4346 | 1.049 | 4339 | 1.05 | | 0.2% | 0.2% |
| 3-day maximum | 1837 | 1.027 | 1835 | 1.03 | | 0.1% | 0.2% |
| 7-day maximum | 1008 | 1.023 | 1006 | 1.02 | | 0.2% | 0.2% |
| 30-day maximum | 429.1 | 0.9627 | 428 | 0.96 | | 0.2% | 0.2% |
| 90-day maximum | 235.7 | 0.8723 | 235 | 0.87 | | 0.2% | 0.2% |
| | | | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 167.6 | 0.2877 | 167.6 | 0.2877 | | 0.0% | 0.0% |
| Date of maximum | 185.8 | 0.26 | 185.8 | 0.26 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.125 | 0.5124 | 5.125 | 0.5124 | | 0.0% | 0.0% |
| Low pulse duration | 19.47 | 1.101 | 19.47 | 1.101 | | 0.0% | 0.0% |
| High pulse count | 4.613 | 0.6989 | 4.625 | 0.6978 | | 0.3% | 0.2% |
| High pulse duration | 1.767 | 0.9643 | 1.755 | 0.9532 | | 0.7% | 1.2% |
| | | | | | Average | 0.2% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 214.4 | 0.9197 | 213.5 | 0.915 | | 0.4% | 0.5% |
| Fall rate | -40.44 | -0.877 | -40.4 | -0.8766 | | 0.1% | 0.0% |
| Number of reversals | 52.2 | 0.2098 | 52.45 | 0.2118 | | 0.5% | 1.0% |
| | | | | | Average | 0.3% | 0.5% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

## Table 9.41 (Continued)

Control Point: P3824 Period: 1934-2013

| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 79.87 | 1.334 | 79.73 | 1.335 | | 0.2% | 0.1% |
| February | 88.76 | 1.141 | 88.5 | 1.14 | | 0.3% | 0.1% |
| March | 89.55 | 1.008 | 89.38 | 1.007 | | 0.2% | 0.1% |
| April | 100.4 | 1.12 | 99.99 | 1.116 | | 0.4% | 0.4% |
| May | 130.9 | 0.9941 | 130.5 | 0.9935 | | 0.3% | 0.1% |
| June | 164.2 | 1.789 | 163.8 | 1.786 | | 0.2% | 0.2% |
| July | 119.1 | 2.09 | 118.9 | 2.093 | | 0.2% | 0.1% |
| August | 106.1 | 2.402 | 105.9 | 2.401 | | 0.2% | 0.0% |
| September | 98.33 | 1.622 | 98 | 1.621 | | 0.3% | 0.1% |
| October | 124.6 | 1.302 | 124.4 | 1.302 | | 0.2% | 0.0% |
| November | 94.91 | 1.238 | 94.71 | 1.237 | | 0.2% | 0.1% |
| December | 77.88 | 1.141 | 77.8 | 1.141 | | 0.1% | 0.0% |
| | | | | | Average | 0.2% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 3.278 | 1.322 | 3.278 | 1.322 | | 0.0% | 0.0% |
| 3-day minimum | 3.51 | 1.301 | 3.51 | 1.301 | | 0.0% | 0.0% |
| 7-day minimum | 4.29 | 1.243 | 4.29 | 1.243 | | 0.0% | 0.0% |
| 30-day minimum | 11.67 | 0.9616 | 11.67 | 0.9616 | | 0.0% | 0.0% |
| 90-day minimum | 27.76 | 0.9195 | 27.74 | 0.9188 | | 0.1% | 0.1% |
| 1-day maximum | 4346 | 1.049 | 4337 | 1.051 | | 0.2% | 0.2% |
| 3-day maximum | 1837 | 1.027 | 1833 | 1.029 | | 0.2% | 0.2% |
| 7-day maximum | 1008 | 1.023 | 1005 | 1.024 | | 0.3% | 0.1% |
| 30-day maximum | 429.1 | 0.9627 | 428 | 0.9628 | | 0.3% | 0.0% |
| 90-day maximum | 235.7 | 0.8723 | 235.1 | 0.8725 | | 0.3% | 0.0% |
| | | | | | Average | 0.1% | 0.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 167.6 | 0.2877 | 167.6 | 0.2877 | | 0.0% | 0.0% |
| Date of maximum | 185.8 | 0.26 | 185.8 | 0.26 | | 0.0% | 0.0% |
| | | | | | Average | 0.0% | 0.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 5.125 | 0.5124 | 5.138 | 0.5152 | | 0.3% | 0.5% |
| Low pulse duration | 19.47 | 1.101 | 19.44 | 1.102 | | 0.2% | 0.1% |
| High pulse count | 4.613 | 0.6989 | 4.613 | 0.6989 | | 0.0% | 0.0% |
| High pulse duration | 1.767 | 0.9643 | 1.764 | 0.9663 | | 0.2% | 0.2% |
| | | | | | Average | 0.1% | 0.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 214.4 | 0.9197 | 208.1 | 0.9156 | | 2.9% | 0.4% |
| Fall rate | -40.44 | -0.877 | -40.6 | -0.8778 | | 0.4% | 0.1% |
| Number of reversals | 52.2 | 0.2098 | 54.76 | 0.2238 | | 4.9% | 6.7% |
| | | | | | Average | 2.7% | 2.4% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.42 DHRAM results at Control Point CP28 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

Control Point: CP28 Period: 1934-2013

| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 202.5 | 1.375 | 119.1 | 1.3 | | 41.2% | 5.5% |
| February | 216.5 | 1.106 | 128 | 1.127 | | 40.9% | 1.9% |
| March | 194.9 | 0.928 | 107.6 | 0.8855 | | 44.8% | 4.6% |
| April | 235.4 | 1.156 | 138.2 | 1.309 | | 41.3% | 13.2% |
| May | 299.9 | 1.038 | 167.6 | 1.133 | | 44.1% | 9.2% |
| June | 410.9 | 2.149 | 273.4 | 2.853 | | 33.5% | 32.8% |
| July | 272.2 | 2.104 | 157.7 | 2.061 | | 42.1% | 2.0% |
| August | 213.6 | 1.914 | 131 | 1.71 | | 38.7% | 10.7% |
| September | 260.9 | 1.529 | 170.4 | 1.687 | | 34.7% | 10.3% |
| October | 307.1 | 1.299 | 200 | 1.669 | | 34.9% | 28.5% |
| November | 242.8 | 1.353 | 145.8 | 1.498 | | 40.0% | 10.7% |
| December | 204 | 1.341 | 125.6 | 1.384 | | 38.4% | 3.2% |
| | | | | | Average | 39.5% | 11.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 18.11 | 1.027 | 3.63 | 1.52 | | 80.0% | 48.4% |
| 3-day minimum | 19.07 | 1.006 | 9.03 | 1.20 | | 52.6% | 19.5% |
| 7-day minimum | 21.18 | 0.9715 | 13.96 | 1.05 | | 34.1% | 8.4% |
| 30-day minimum | 37.68 | 0.844 | 30.04 | 0.71 | | 20.3% | 15.3% |
| 90-day minimum | 73.36 | 0.7922 | 50.53 | 0.60 | | 31.1% | 24.0% |
| 1-day maximum | 5041 | 0.9953 | 3611 | 1.13 | | 28.4% | 13.9% |
| 3-day maximum | 3533 | 1.009 | 2281 | 1.25 | | 35.4% | 23.5% |
| 7-day maximum | 2414 | 1.064 | 1581 | 1.28 | | 34.5% | 20.0% |
| 30-day maximum | 1010 | 1.093 | 656 | 1.39 | | 35.0% | 27.0% |
| 90-day maximum | 554.8 | 0.9184 | 340 | 1.14 | | 38.7% | 24.1% |
| | | | | | Average | 39.0% | 22.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 195.4 | 0.2762 | 155.8 | 0.238 | | 20.3% | 13.8% |
| Date of maximum | 174.7 | 0.2499 | 184.7 | 0.2659 | | 5.7% | 6.4% |
| | | | | | Average | 13.0% | 10.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.488 | 0.7162 | 7.9 | 0.5145 | | 76.0% | 28.2% |
| Low pulse duration | 21.36 | 0.7974 | 10.54 | 0.9908 | | 50.7% | 24.3% |
| High pulse count | 4.338 | 0.8413 | 4.425 | 0.8981 | | 2.0% | 6.8% |
| High pulse duration | 3.118 | 0.6602 | 2.57 | 0.8257 | | 17.6% | 25.1% |
| | | | | | Average | 36.6% | 21.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 258.7 | 0.9127 | 120.6 | 0.9699 | | 53.4% | 6.3% |
| Fall rate | -53.13 | -0.8737 | -53.53 | -0.8933 | | 0.8% | 2.2% |
| Number of reversals | 64.41 | 0.2866 | 92.3 | 0.2342 | | 43.3% | 18.3% |
| | | | | | Average | 32.5% | 8.9% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 3 |
| Classification | 2 |
| note: | Low risk of impact |

Table 9.42 (Continued)

| Control Point: | CP28 | Period: | 1934-2013 | | | |
|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | |
| January | 202.5 | 1.375 | 161.6 | 0.9816 | 20.2% | 28.6% |
| February | 216.5 | 1.106 | 168.8 | 0.8424 | 22.0% | 23.8% |
| March | 194.9 | 0.928 | 155.4 | 0.6914 | 20.3% | 25.5% |
| April | 235.4 | 1.156 | 196.7 | 1.024 | 16.4% | 11.4% |
| May | 299.9 | 1.038 | 218.2 | 0.8807 | 27.2% | 15.2% |
| June | 410.9 | 2.149 | 307.4 | 2.284 | 25.2% | 6.3% |
| July | 272.2 | 2.104 | 200.5 | 1.745 | 26.3% | 17.1% |
| August | 213.6 | 1.914 | 161.1 | 1.534 | 24.6% | 19.9% |
| September | 260.9 | 1.529 | 200.5 | 1.404 | 23.2% | 8.2% |
| October | 307.1 | 1.299 | 231.6 | 1.097 | 24.6% | 15.6% |
| November | 242.8 | 1.353 | 176.1 | 1.167 | 27.5% | 13.7% |
| December | 204 | 1.341 | 161.3 | 1.119 | 20.9% | 16.6% |
| | | | | Average | 23.2% | 16.8% |
| | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | |
| 1-day minimum | 18.11 | 1.027 | 23.11 | 0.8496 | 27.6% | 17.3% |
| 3-day minimum | 19.07 | 1.006 | 26.34 | 0.8608 | 38.1% | 14.4% |
| 7-day minimum | 21.18 | 0.9715 | 29.38 | 0.8983 | 38.7% | 7.5% |
| 30-day minimum | 37.68 | 0.844 | 45.89 | 0.8062 | 21.8% | 4.5% |
| 90-day minimum | 73.36 | 0.7922 | 75.58 | 0.6971 | 3.0% | 12.0% |
| 1-day maximum | 5041 | 0.9953 | 3788 | 0.9549 | 24.9% | 4.1% |
| 3-day maximum | 3533 | 1.009 | 2464 | 0.9361 | 30.3% | 7.2% |
| 7-day maximum | 2414 | 1.064 | 1691 | 1.046 | 30.0% | 1.7% |
| 30-day maximum | 1010 | 1.093 | 698.9 | 1.16 | 30.8% | 6.1% |
| 90-day maximum | 554.8 | 0.9184 | 385.7 | 0.9083 | 30.5% | 1.1% |
| | | | | Average | 27.6% | 7.6% |
| | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | |
| Date of minimum | 195.4 | 0.2762 | 195.4 | 0.2602 | 0.0% | 5.8% |
| Date of maximum | 174.7 | 0.2499 | 185.4 | 0.2322 | 6.1% | 7.1% |
| | | | | Average | 3.1% | 6.4% |
| | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | |
| Low pulse count | 4.488 | 0.7162 | 5.625 | 0.8151 | 25.3% | 13.8% |
| Low pulse duration | 21.36 | 0.7974 | 16.63 | 0.9694 | 22.1% | 21.6% |
| High pulse count | 4.338 | 0.8413 | 4.863 | 0.8159 | 12.1% | 3.0% |
| High pulse duration | 3.118 | 0.6602 | 2.569 | 0.6806 | 17.6% | 3.1% |
| | | | | Average | 19.3% | 10.4% |
| | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | |
| Rise rate | 258.7 | 0.9127 | 139.9 | 0.7863 | 45.9% | 13.8% |
| Fall rate | -53.13 | -0.8737 | -52.2 | -0.8772 | 1.8% | 0.4% |
| Number of reversals | 64.41 | 0.2866 | 94.79 | 0.2831 | 47.2% | 1.2% |
| | | | | Average | 31.6% | 5.2% |
| | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

Table 9.43 DHRAM results at Control Point CP29 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | CP29 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 336.7 | 1.394 | 199.2 | 1.681 | | 40.8% | 20.6% |
| February | 344.1 | 1.001 | 193 | 1.181 | | 43.9% | 18.0% |
| March | 283.4 | 0.8359 | 142.1 | 0.9389 | | 49.9% | 12.3% |
| April | 343 | 0.9815 | 198.8 | 1.19 | | 42.0% | 21.2% |
| May | 475.6 | 1.029 | 296.9 | 1.2 | | 37.6% | 16.6% |
| June | 615.6 | 1.844 | 434.4 | 2.314 | | 29.4% | 25.5% |
| July | 359.7 | 1.99 | 224.6 | 2.119 | | 37.6% | 6.5% |
| August | 272.6 | 1.938 | 165.4 | 2.202 | | 39.3% | 13.6% |
| September | 423.5 | 1.518 | 284.6 | 1.882 | | 32.8% | 24.0% |
| October | 489 | 1.253 | 336.1 | 1.564 | | 31.3% | 24.8% |
| November | 407.9 | 1.378 | 275.8 | 1.642 | | 32.4% | 19.2% |
| December | 314.3 | 1.314 | 203.1 | 1.535 | | 35.4% | 16.8% |
| | | | | | Average | 37.7% | 18.3% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 20.53 | 1.405 | 1.04 | 0.73 | | 94.9% | 47.9% |
| 3-day minimum | 21.47 | 1.387 | 1.93 | 1.06 | | 91.0% | 23.8% |
| 7-day minimum | 24.13 | 1.343 | 5.05 | 1.50 | | 79.1% | 11.3% |
| 30-day minimum | 45.31 | 1.22 | 24.54 | 1.02 | | 45.8% | 16.3% |
| 90-day minimum | 102.1 | 0.87 | 58.13 | 0.83 | | 43.1% | 4.5% |
| 1-day maximum | 7854 | 0.919 | 6989 | 0.98 | | 11.0% | 7.0% |
| 3-day maximum | 5249 | 0.9317 | 4136 | 1.05 | | 21.2% | 13.0% |
| 7-day maximum | 3634 | 0.9624 | 2798 | 1.09 | | 23.0% | 13.2% |
| 30-day maximum | 1548 | 0.9543 | 1147 | 1.14 | | 25.9% | 19.8% |
| 90-day maximum | 835.4 | 0.834 | 567 | 1.02 | | 32.1% | 21.8% |
| | | | | | Average | 46.7% | 17.9% |
| | | | | | Score | 1 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 198.9 | 0.2258 | 76.73 | 0.2266 | | 61.4% | 0.4% |
| Date of maximum | 189.9 | 0.2433 | 182 | 0.2556 | | 4.2% | 5.1% |
| | | | | | Average | 32.8% | 2.7% |
| | | | | | Score | 2 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.45 | 0.7379 | 11 | 0.4819 | | 147.2% | 34.7% |
| Low pulse duration | 22.49 | 0.9741 | 11.8 | 2.744 | | 47.5% | 181.7% |
| High pulse count | 4.988 | 0.7505 | 5.338 | 0.8191 | | 7.0% | 9.1% |
| High pulse duration | 2.792 | 0.5961 | 2.294 | 0.6469 | | 17.8% | 8.5% |
| | | | | | Average | 54.9% | 58.5% |
| | | | | | Score | 1 | 1 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 380.7 | 0.8352 | 243.7 | 0.8648 | | 36.0% | 3.5% |
| Fall rate | -91.22 | -0.7876 | -112.4 | -0.7652 | | 23.2% | 2.8% |
| Number of reversals | 61.84 | 0.2761 | 92.16 | 0.2749 | | 49.0% | 0.4% |
| | | | | | Average | 36.1% | 2.3% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 6 |
| Classification | | 3 |
| note: | Moderate risk of impact | |

Table 9.43 (Continued)

Control Point: CP29 Period: 1934-2013

| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 336.7 | 1.394 | 268.7 | 1.235 | | 20.2% | 11.4% |
| February | 344.1 | 1.001 | 259.9 | 0.8633 | | 24.5% | 13.8% |
| March | 283.4 | 0.8359 | 217.5 | 0.6602 | | 23.3% | 21.0% |
| April | 343 | 0.9815 | 276.4 | 0.9009 | | 19.4% | 8.2% |
| May | 475.6 | 1.029 | 353.8 | 1.011 | | 25.6% | 1.7% |
| June | 615.6 | 1.844 | 482.1 | 1.941 | | 21.7% | 5.3% |
| July | 359.7 | 1.99 | 268.8 | 1.83 | | 25.3% | 8.0% |
| August | 272.6 | 1.938 | 206.8 | 1.75 | | 24.1% | 9.7% |
| September | 423.5 | 1.518 | 325.5 | 1.608 | | 23.1% | 5.9% |
| October | 489 | 1.253 | 387.2 | 1.219 | | 20.8% | 2.7% |
| November | 407.9 | 1.378 | 322 | 1.343 | | 21.1% | 2.5% |
| December | 314.3 | 1.314 | 255.5 | 1.221 | | 18.7% | 7.1% |
| | | | | | Average | 22.3% | 8.1% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 20.53 | 1.405 | 20.24 | 1.413 | | 1.4% | 0.6% |
| 3-day minimum | 21.47 | 1.387 | 27.98 | 1.237 | | 30.3% | 10.8% |
| 7-day minimum | 24.13 | 1.343 | 30.34 | 1.22 | | 25.7% | 9.2% |
| 30-day minimum | 45.31 | 1.22 | 50.96 | 1.129 | | 12.5% | 7.5% |
| 90-day minimum | 102.1 | 0.87 | 98.1 | 0.8288 | | 3.9% | 4.7% |
| 1-day maximum | 7854 | 0.919 | 6974 | 0.9511 | | 11.2% | 3.5% |
| 3-day maximum | 5249 | 0.9317 | 4217 | 0.9708 | | 19.7% | 4.2% |
| 7-day maximum | 3634 | 0.9624 | 2831 | 0.9927 | | 22.1% | 3.1% |
| 30-day maximum | 1548 | 0.9543 | 1168 | 1.036 | | 24.5% | 8.6% |
| 90-day maximum | 835.4 | 0.834 | 617.2 | 0.8726 | | 26.1% | 4.6% |
| | | | | | Average | 17.7% | 5.7% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 198.9 | 0.2258 | 188.6 | 0.2187 | | 5.2% | 3.1% |
| Date of maximum | 189.9 | 0.2433 | 189.1 | 0.2603 | | 0.4% | 7.0% |
| | | | | | Average | 2.8% | 5.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.45 | 0.7379 | 7.3 | 0.9442 | | 64.0% | 28.0% |
| Low pulse duration | 22.49 | 0.9741 | 15.02 | 1.311 | | 33.2% | 34.6% |
| High pulse count | 4.988 | 0.7505 | 5.388 | 0.7642 | | 8.0% | 1.8% |
| High pulse duration | 2.792 | 0.5961 | 2.186 | 0.5465 | | 21.7% | 8.3% |
| | | | | | Average | 31.7% | 18.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 380.7 | 0.8352 | 254.3 | 0.7573 | | 33.2% | 9.3% |
| Fall rate | -91.22 | -0.7876 | -105.4 | -0.7886 | | 15.5% | 0.1% |
| Number of reversals | 61.84 | 0.2761 | 108.6 | 0.291 | | 75.6% | 5.4% |
| | | | | | Average | 41.5% | 5.0% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

Table 9.44 DHRAM results at Control Point CP32 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

| Control Point: | CP32 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 389.9 | 1.42 | 255.6 | 1.618 | | 34.4% | 13.9% |
| February | 400.2 | 0.9972 | 254.7 | 1.102 | | 36.4% | 10.5% |
| March | 326.8 | 0.7825 | 188.6 | 0.8287 | | 42.3% | 5.9% |
| April | 405.9 | 0.9906 | 260.5 | 1.145 | | 35.8% | 15.6% |
| May | 555.9 | 0.937 | 368.4 | 1.031 | | 33.7% | 10.0% |
| June | 728.8 | 1.757 | 530.5 | 2.128 | | 27.2% | 21.1% |
| July | 434 | 1.695 | 285.2 | 1.715 | | 34.3% | 1.2% |
| August | 343.2 | 1.674 | 236.4 | 1.741 | | 31.1% | 4.0% |
| September | 501.7 | 1.387 | 359.4 | 1.595 | | 28.4% | 15.0% |
| October | 555.6 | 1.191 | 403.6 | 1.385 | | 27.4% | 16.3% |
| November | 476.6 | 1.34 | 345.6 | 1.503 | | 27.5% | 12.2% |
| December | 363.3 | 1.238 | 255.7 | 1.346 | | 29.6% | 8.7% |
| | | | | | Average | 32.3% | 11.2% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 35.68 | 0.9582 | 17.19 | 0.63 | | 51.8% | 34.7% |
| 3-day minimum | 37.31 | 0.9518 | 19.16 | 0.60 | | 48.6% | 37.5% |
| 7-day minimum | 40.89 | 0.9096 | 23.61 | 0.68 | | 42.3% | 25.8% |
| 30-day minimum | 71.03 | 0.8185 | 48.90 | 0.67 | | 31.2% | 18.5% |
| 90-day minimum | 143.3 | 0.6597 | 96.29 | 0.57 | | 32.8% | 14.1% |
| 1-day maximum | 4866 | 0.9222 | 4044 | 0.99 | | 16.9% | 7.7% |
| 3-day maximum | 4403 | 0.9237 | 3360 | 1.05 | | 23.7% | 14.1% |
| 7-day maximum | 3602 | 0.9432 | 2724 | 1.08 | | 24.4% | 14.0% |
| 30-day maximum | 1697 | 0.9229 | 1281 | 1.09 | | 24.5% | 17.6% |
| 90-day maximum | 944.2 | 0.8146 | 673 | 0.94 | | 28.7% | 15.5% |
| | | | | | Average | 32.5% | 19.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 194 | 0.2631 | 173.7 | 0.2584 | | 10.5% | 1.8% |
| Date of maximum | 193.5 | 0.2506 | 187.8 | 0.25 | | 2.9% | 0.2% |
| | | | | | Average | 6.7% | 1.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.7 | 0.6355 | 8.95 | 0.5019 | | 90.4% | 21.0% |
| Low pulse duration | 19.43 | 0.7268 | 9.885 | 0.7986 | | 49.1% | 9.9% |
| High pulse count | 2.838 | 0.9032 | 3.613 | 0.8759 | | 27.3% | 3.0% |
| High pulse duration | 6.941 | 0.5747 | 4.922 | 0.7027 | | 29.1% | 22.3% |
| | | | | | Average | 49.0% | 14.0% |
| | | | | | Score | 1 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 166.1 | 0.8625 | 140.2 | 0.7917 | | 15.6% | 8.2% |
| Fall rate | -50.34 | -0.7761 | -60.94 | -0.7334 | | 21.1% | 5.5% |
| Number of reversals | 52.54 | 0.1982 | 88.53 | 0.1769 | | 68.5% | 10.7% |
| | | | | | Average | 35.1% | 8.2% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 2 |
| Classification | 2 |
| note: | Low risk of impact |

## Table 9.44 (Continued)

| Control Point: | CP32 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 389.9 | 1.42 | 321.1 | 1.278 | | 17.6% | 10.0% |
| February | 400.2 | 0.9972 | 315.4 | 0.8852 | | 21.2% | 11.2% |
| March | 326.8 | 0.7825 | 259.4 | 0.6351 | | 20.6% | 18.8% |
| April | 405.9 | 0.9906 | 333.5 | 0.9214 | | 17.8% | 7.0% |
| May | 555.9 | 0.937 | 424.4 | 0.8984 | | 23.7% | 4.1% |
| June | 728.8 | 1.757 | 578.1 | 1.839 | | 20.7% | 4.7% |
| July | 434 | 1.695 | 333.7 | 1.511 | | 23.1% | 10.9% |
| August | 343.2 | 1.674 | 275.3 | 1.464 | | 19.8% | 12.5% |
| September | 501.7 | 1.387 | 396.4 | 1.419 | | 21.0% | 2.3% |
| October | 555.6 | 1.191 | 447.7 | 1.138 | | 19.4% | 4.5% |
| November | 476.6 | 1.34 | 387.9 | 1.289 | | 18.6% | 3.8% |
| December | 363.3 | 1.238 | 303.4 | 1.131 | | 16.5% | 8.6% |
| | | | | | Average | 20.0% | 8.2% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 35.68 | 0.9582 | 35.62 | 0.9888 | | 0.2% | 3.2% |
| 3-day minimum | 37.31 | 0.9518 | 42.78 | 0.8983 | | 14.7% | 5.6% |
| 7-day minimum | 40.89 | 0.9096 | 46.48 | 0.8651 | | 13.7% | 4.9% |
| 30-day minimum | 71.03 | 0.8185 | 74.66 | 0.7771 | | 5.1% | 5.1% |
| 90-day minimum | 143.3 | 0.6597 | 135.8 | 0.6101 | | 5.2% | 7.5% |
| 1-day maximum | 4866 | 0.9222 | 4035 | 0.9122 | | 17.1% | 1.1% |
| 3-day maximum | 4403 | 0.9237 | 3330 | 0.9366 | | 24.4% | 1.4% |
| 7-day maximum | 3602 | 0.9432 | 2733 | 0.9785 | | 24.1% | 3.7% |
| 30-day maximum | 1697 | 0.9229 | 1302 | 0.9927 | | 23.3% | 7.6% |
| 90-day maximum | 944.2 | 0.8146 | 718.3 | 0.8325 | | 23.9% | 2.2% |
| | | | | | Average | 15.2% | 4.2% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 194 | 0.2631 | 196.6 | 0.2621 | | 1.3% | 0.4% |
| Date of maximum | 193.5 | 0.2506 | 193.1 | 0.2413 | | 0.2% | 3.7% |
| | | | | | Average | 0.8% | 2.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 4.7 | 0.6355 | 5.688 | 0.7174 | | 21.0% | 12.9% |
| Low pulse duration | 19.43 | 0.7268 | 16.2 | 0.8749 | | 16.6% | 20.4% |
| High pulse count | 2.838 | 0.9032 | 3.763 | 0.9082 | | 32.6% | 0.6% |
| High pulse duration | 6.941 | 0.5747 | 4.677 | 0.6419 | | 32.6% | 11.7% |
| | | | | | Average | 25.7% | 11.4% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 166.1 | 0.8625 | 140.9 | 0.75 | | 15.2% | 13.0% |
| Fall rate | -50.34 | -0.7761 | -59.79 | -0.7273 | | 18.8% | 6.3% |
| Number of reversals | 52.54 | 0.1982 | 98.28 | 0.2412 | | 87.1% | 21.7% |
| | | | | | Average | 40.3% | 13.7% |
| | | | | | Score | 0 | 0 |

| | | |
|---|---|---|
| Total Point | | 1 |
| Classification | | 2 |
| note: | Low risk of impact | |

Table 9.45 DHRAM results at Control Point CP35 (Naturalized vs. Regulated Flows under SB3 EFS with Senior Priority)

| Control Point: | CP35 | Period: | 1934-2013 | | | | |
|---|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 94.84 | 2.25 | 94.23 | 2.262 | | 0.6% | 0.5% |
| February | 96.71 | 1.479 | 95.74 | 1.488 | | 1.0% | 0.6% |
| March | 65.14 | 1.775 | 63.7 | 1.806 | | 2.2% | 1.7% |
| April | 141 | 1.841 | 139.1 | 1.859 | | 1.3% | 1.0% |
| May | 204.2 | 1.613 | 201.1 | 1.631 | | 1.5% | 1.1% |
| June | 211.8 | 1.976 | 208.4 | 2.001 | | 1.6% | 1.3% |
| July | 135 | 2.715 | 133 | 2.745 | | 1.5% | 1.1% |
| August | 60.42 | 2.136 | 59.11 | 2.165 | | 2.2% | 1.4% |
| September | 159.5 | 1.97 | 157.8 | 1.986 | | 1.1% | 0.8% |
| October | 163.8 | 1.942 | 162.5 | 1.954 | | 0.8% | 0.6% |
| November | 113.6 | 1.855 | 112.7 | 1.866 | | 0.8% | 0.6% |
| December | 94.16 | 2.414 | 93.53 | 2.427 | | 0.7% | 0.5% |
| | | | | | Average | 1.3% | 0.9% |
| | | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 2.164 | 1.2 | 2.164 | 1.2 | | 0.0% | 0.0% |
| 3-day minimum | 2.337 | 1.153 | 2.337 | 1.153 | | 0.0% | 0.0% |
| 7-day minimum | 2.828 | 1.081 | 2.828 | 1.081 | | 0.0% | 0.0% |
| 30-day minimum | 7.356 | 0.8235 | 7.298 | 0.8192 | | 0.8% | 0.5% |
| 90-day minimum | 20.65 | 0.6713 | 20.19 | 0.6677 | | 2.2% | 0.5% |
| 1-day maximum | 2775 | 1.109 | 2768 | 1.111 | | 0.3% | 0.2% |
| 3-day maximum | 2293 | 1.045 | 2286 | 1.047 | | 0.3% | 0.2% |
| 7-day maximum | 1659 | 1.01 | 1653 | 1.014 | | 0.4% | 0.4% |
| 30-day maximum | 690.2 | 0.9501 | 686.1 | 0.9551 | | 0.6% | 0.5% |
| 90-day maximum | 321.9 | 0.8916 | 318.9 | 0.8968 | | 0.9% | 0.6% |
| | | | | | Average | 0.5% | 0.3% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 180.6 | 0.2573 | 180.6 | 0.2573 | | 0.0% | 0.0% |
| Date of maximum | 198.4 | 0.2498 | 200.2 | 0.253 | | 0.9% | 1.3% |
| | | | | | Average | 0.5% | 0.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 7.213 | 0.5371 | 7.5 | 0.543 | | 4.0% | 1.1% |
| Low pulse duration | 12.74 | 0.69 | 12.41 | 0.6586 | | 2.6% | 4.6% |
| High pulse count | 2.925 | 0.8511 | 2.925 | 0.8511 | | 0.0% | 0.0% |
| High pulse duration | 5.651 | 0.6739 | 5.627 | 0.6786 | | 0.4% | 0.7% |
| | | | | | Average | 1.7% | 1.6% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 99.08 | 0.9965 | 96.6 | 1.004 | | 2.5% | 0.8% |
| Fall rate | -25.62 | -0.8949 | -25.81 | -0.8943 | | 0.7% | 0.1% |
| Number of reversals | 63.75 | 0.1421 | 68.25 | 0.1297 | | 7.1% | 8.7% |
| | | | | | Average | 3.4% | 3.2% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

Table 9.46 DHRAM results at Control Point CP37 (Naturalized vs. Regulated Flows under SB3 EFS with Junior and Senior Priority)

Control Point: CP37 Period: 1934-2013

| IHA statistics group | Naturalized | | Regulated (Junior) | | | Absolute Chages | |
|---|---|---|---|---|---|---|---|
| | Mean(cfs) | CV | Mean(cfs) | CV | | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | | |
| January | 545.3 | 1.393 | 423.6 | 1.506 | | 22.3% | 8.1% |
| February | 598.3 | 1.103 | 464.3 | 1.2 | | 22.4% | 8.8% |
| March | 470.3 | 1.013 | 338 | 1.191 | | 28.1% | 17.6% |
| April | 653.2 | 1.158 | 512.3 | 1.3 | | 21.6% | 12.3% |
| May | 959.4 | 1.063 | 776.6 | 1.141 | | 19.1% | 7.3% |
| June | 1164 | 1.746 | 968 | 1.946 | | 16.8% | 11.5% |
| July | 740.1 | 1.905 | 592.5 | 2.016 | | 19.9% | 5.8% |
| August | 423.8 | 1.504 | 320.1 | 1.607 | | 24.5% | 6.8% |
| September | 910.7 | 1.724 | 773.9 | 1.928 | | 15.0% | 11.8% |
| October | 957.4 | 1.512 | 816.2 | 1.681 | | 14.7% | 11.2% |
| November | 729.4 | 1.377 | 607.4 | 1.481 | | 16.7% | 7.6% |
| December | 525.8 | 1.523 | 426.9 | 1.664 | | 18.8% | 9.3% |
| | | | | | Average | 20.0% | 9.8% |
| | | | | | Score | 1 | 0 |
| Parameter Group #2 | | | | | | | |
| 1-day minimum | 55.35 | 0.7719 | 23.82 | 1.00 | | 57.0% | 29.7% |
| 3-day minimum | 57.47 | 0.7669 | 30.77 | 0.89 | | 46.5% | 16.7% |
| 7-day minimum | 62.65 | 0.764 | 42.92 | 0.76 | | 31.5% | 0.1% |
| 30-day minimum | 101.6 | 0.7637 | 78.69 | 0.72 | | 22.5% | 5.8% |
| 90-day minimum | 195.6 | 0.6416 | 149.20 | 0.61 | | 23.7% | 5.2% |
| 1-day maximum | 7615 | 1.066 | 7068 | 1.12 | | 7.2% | 4.8% |
| 3-day maximum | 6839 | 1.022 | 6169 | 1.09 | | 9.8% | 6.2% |
| 7-day maximum | 5854 | 1.043 | 5221 | 1.12 | | 10.8% | 7.0% |
| 30-day maximum | 2975 | 0.9302 | 2590 | 1.00 | | 12.9% | 7.8% |
| 90-day maximum | 1569 | 0.8147 | 1317 | 0.88 | | 16.1% | 8.0% |
| | | | | | Average | 23.8% | 9.1% |
| | | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | | |
| Date of minimum | 210.6 | 0.2656 | 204.5 | 0.2329 | | 2.9% | 12.3% |
| Date of maximum | 197.8 | 0.2435 | 197.8 | 0.2396 | | 0.0% | 1.6% |
| | | | | | Average | 1.4% | 7.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | | |
| Low pulse count | 3.788 | 0.6463 | 6.6 | 0.5174 | | 74.2% | 19.9% |
| Low pulse duration | 24.92 | 0.7837 | 15.46 | 1.029 | | 38.0% | 31.3% |
| High pulse count | 1.963 | 0.9811 | 2.05 | 0.9597 | | 4.4% | 2.2% |
| High pulse duration | 10.75 | 0.5514 | 9.509 | 0.5374 | | 11.5% | 2.5% |
| | | | | | Average | 32.0% | 14.0% |
| | | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | | |
| Rise rate | 168.7 | 0.9088 | 155.1 | 0.8717 | | 8.1% | 4.1% |
| Fall rate | -70.4 | -0.8615 | -76.07 | -0.8259 | | 8.1% | 4.1% |
| Number of reversals | 43.9 | 0.1467 | 69.63 | 0.1505 | | 58.6% | 2.6% |
| | | | | | Average | 24.9% | 3.6% |
| | | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 1 |
| Classification | 2 |
| note: | Low risk of impact |

## Table 9.46 (Continued)

| Control Point: | CP37 | Period: | 1934-2013 | | | |
|---|---|---|---|---|---|---|
| IHA statistics group | Naturalzied | | Regulated (Senior) | | Absolute Chages | |
| | Mean(cfs) | CV | Mean(cfs) | CV | Mean(%) | CV(%) |
| Parameter Group #1 | | | | | | |
| January | 545.3 | 1.393 | 481.8 | 1.319 | 11.6% | 5.3% |
| February | 598.3 | 1.103 | 519.5 | 1.079 | 13.2% | 2.2% |
| March | 470.3 | 1.013 | 402.9 | 1.001 | 14.3% | 1.2% |
| April | 653.2 | 1.158 | 580.9 | 1.154 | 11.1% | 0.3% |
| May | 959.4 | 1.063 | 829.4 | 1.072 | 13.6% | 0.8% |
| June | 1164 | 1.746 | 1015 | 1.802 | 12.8% | 3.2% |
| July | 740.1 | 1.905 | 640.4 | 1.888 | 13.5% | 0.9% |
| August | 423.8 | 1.504 | 357.5 | 1.373 | 15.6% | 8.7% |
| September | 910.7 | 1.724 | 810.7 | 1.842 | 11.0% | 6.8% |
| October | 957.4 | 1.512 | 856.3 | 1.556 | 10.6% | 2.9% |
| November | 729.4 | 1.377 | 646.7 | 1.367 | 11.3% | 0.7% |
| December | 525.8 | 1.523 | 470.1 | 1.503 | 10.6% | 1.3% |
| | | | | Average | 12.4% | 2.9% |
| | | | | Score | 0 | 0 |
| Parameter Group #2 | | | | | | |
| 1-day minimum | 55.35 | 0.7719 | 46.83 | 0.8259 | 15.4% | 7.0% |
| 3-day minimum | 57.47 | 0.7669 | 58.91 | 0.7809 | 2.5% | 1.8% |
| 7-day minimum | 62.65 | 0.764 | 67.41 | 0.7669 | 7.6% | 0.4% |
| 30-day minimum | 101.6 | 0.7637 | 104.7 | 0.7539 | 3.1% | 1.3% |
| 90-day minimum | 195.6 | 0.6416 | 187.7 | 0.6235 | 4.0% | 2.8% |
| 1-day maximum | 7615 | 1.066 | 7062 | 1.095 | 7.3% | 2.7% |
| 3-day maximum | 6839 | 1.022 | 6169 | 1.062 | 9.8% | 3.9% |
| 7-day maximum | 5854 | 1.043 | 5248 | 1.093 | 10.4% | 4.8% |
| 30-day maximum | 2975 | 0.9302 | 2626 | 0.9716 | 11.7% | 4.5% |
| 90-day maximum | 1569 | 0.8147 | 1363 | 0.8336 | 13.1% | 2.3% |
| | | | | Average | 8.5% | 3.2% |
| | | | | Score | 0 | 0 |
| Parameter Group #3 | | | | | | |
| Date of minimum | 210.6 | 0.2656 | 215.3 | 0.2399 | 2.2% | 9.7% |
| Date of maximum | 197.8 | 0.2435 | 194.8 | 0.2487 | 1.5% | 2.1% |
| | | | | Average | 1.9% | 5.9% |
| | | | | Score | 0 | 0 |
| Parameter Group #4 | | | | | | |
| Low pulse count | 3.788 | 0.6463 | 4.6 | 0.6449 | 21.4% | 0.2% |
| Low pulse duration | 24.92 | 0.7837 | 20.67 | 0.8932 | 17.1% | 14.0% |
| High pulse count | 1.963 | 0.9811 | 2.125 | 0.96 | 8.3% | 2.2% |
| High pulse duration | 10.75 | 0.5514 | 9.03 | 0.5629 | 16.0% | 2.1% |
| | | | | Average | 15.7% | 4.6% |
| | | | | Score | 0 | 0 |
| Parameter Group #5 | | | | | | |
| Rise rate | 168.7 | 0.9088 | 157.9 | 0.8738 | 6.4% | 3.9% |
| Fall rate | -70.4 | -0.8615 | -73.36 | -0.8332 | 4.2% | 3.3% |
| Number of reversals | 43.9 | 0.1467 | 70.21 | 0.2199 | 59.9% | 49.9% |
| | | | | Average | 23.5% | 19.0% |
| | | | | Score | 0 | 0 |

| | |
|---|---|
| Total Point | 0 |
| Classification | 1 |
| note: | Un-impacted condition |

The annual median values at the fifteen control points are extracted from the naturalized and two different regulated flows under SB3 EFSs with a junior and a senior priority to all other water rights. The three duration curves are plotted to compare the hydrologic states of each flow for the period 1934-2013 at the fifteen control points.

Figure 9.11 shows the hydrologic states of the three different flows at the control point CP01. The flow duration curves of both the regulated flows are slightly different from the naturalized flows, but both are almost similar. This means that the regulated flow regime is not changed by EFS with a senior priority at the control point.

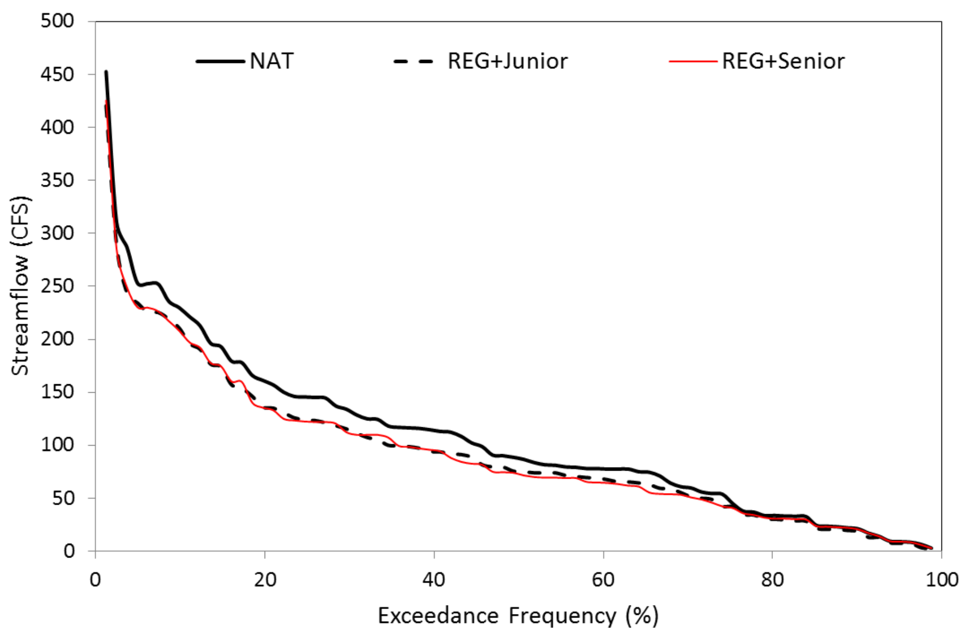



Figure 9.11 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP01

Figure 9.12 shows the hydrologic states of the three different flows at the control point CP02. The flow duration curves of both the regulated flows are nearly similar to the naturalized flows, and both are also same like the control point CP01. This is because there are a few existing water rights upstream of the control point.

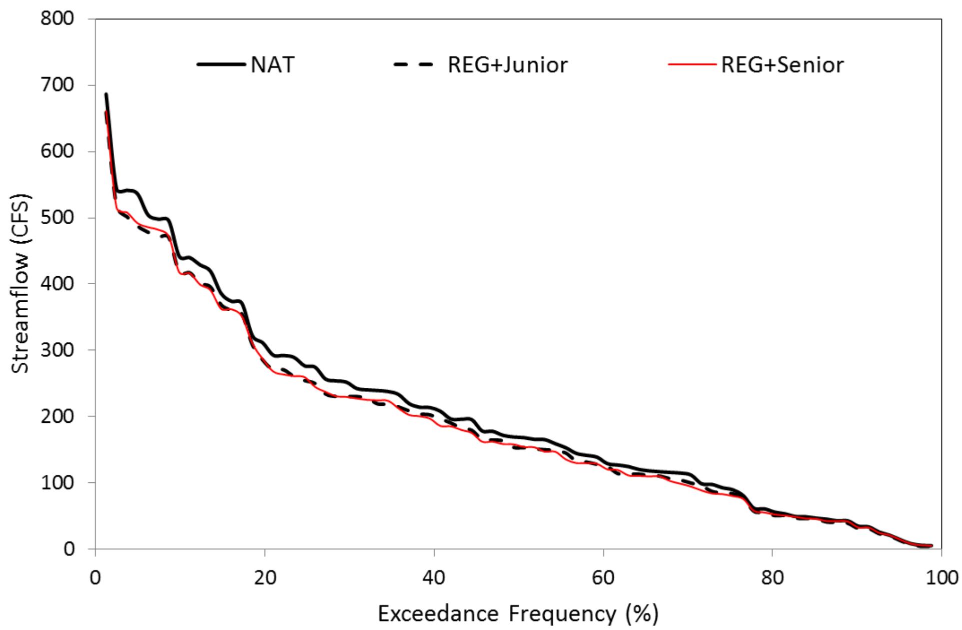



Figure 9.12 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP02

Figure 9.13 presents the hydrologic states of the three different flows at the control point CP08. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are perfectly same. This are considered there are no existing water rights upstream of the control point.

Figure 9.14 presents the hydrologic states of the three different flows at the control point CP10. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are almost same. This means that there are no existing water uses upstream of the control point.

Figure 9.15 presents the hydrologic states of the three different flows at the control point CP11. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are almost similar like CP08 and CP10.

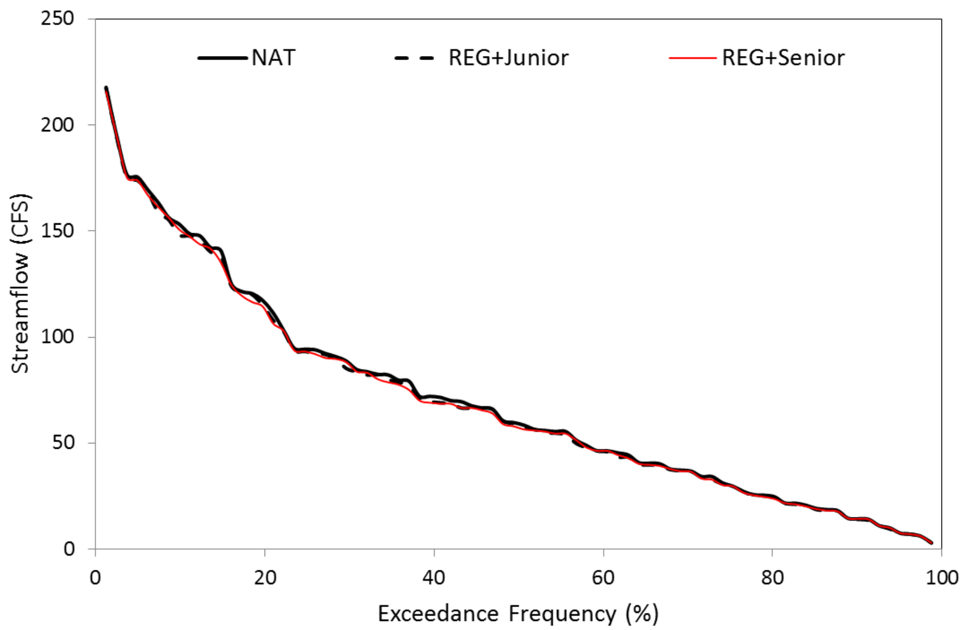



Figure 9.13 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP08

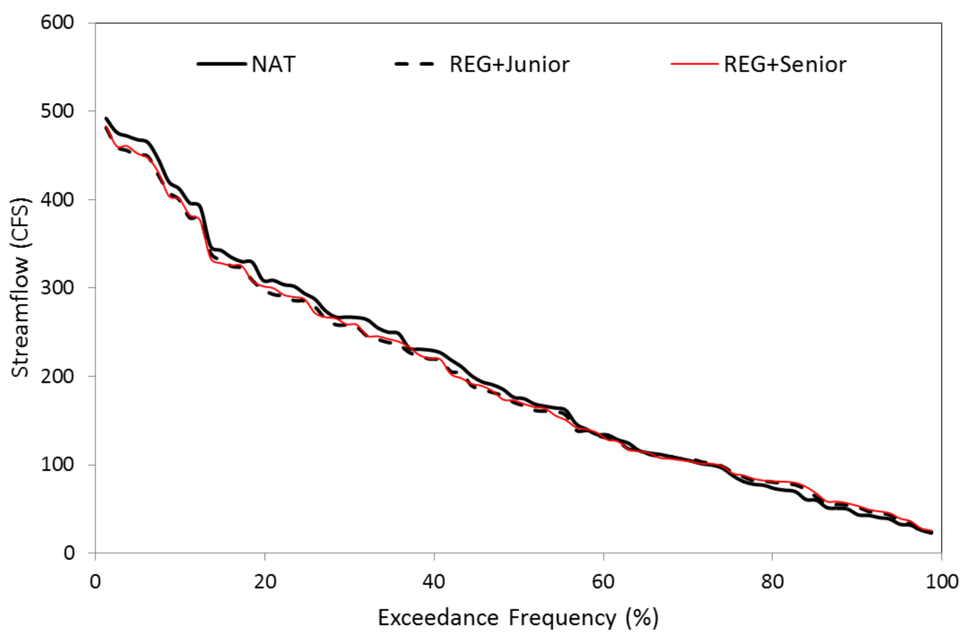



Figure 9.14 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP10

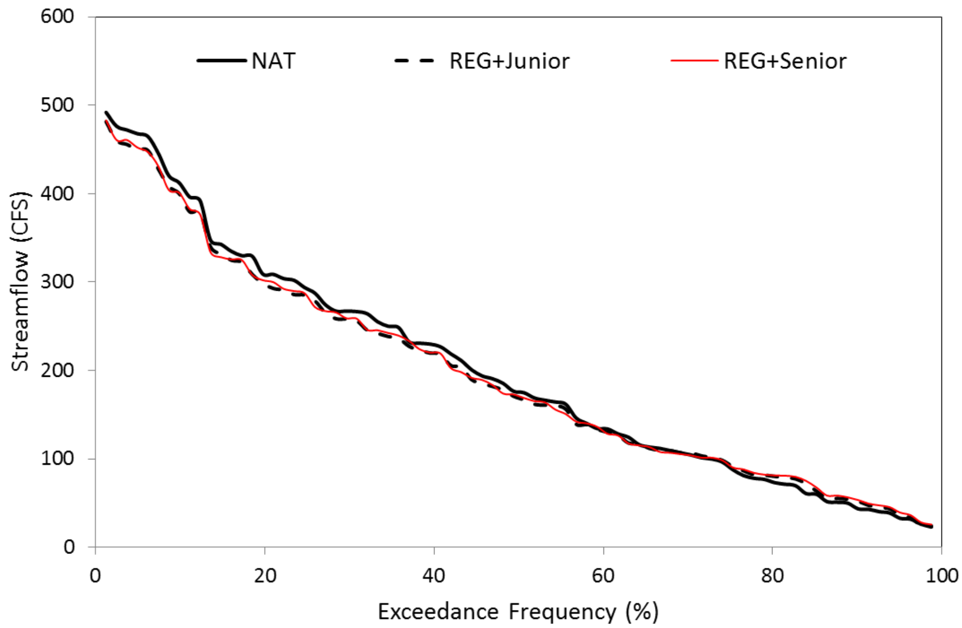



Figure 9.15 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP11

Figure 9.16 presents the hydrologic states of the three different flows at the control point C38461. The flow duration curves of both the regulated flows are totally different from the naturalized flows, but both are also different. There are several hydropower water rights at the Canyon Lake and related lakes that are located upstream of the control points C38461, CP14, and CP15 in the Guadalupe River Basin. Most flows, used for hydropower should be fully returned to the downstream, and these flows can be used for other water rights. This shows that SB3 EFS can tremendously improve the flow regimes of regulated flow by modifying a senior priority. However, the alteration between the naturalized flows and regulated flows with a senior priority is higher than with a junior priority in the DHRAM analysis at the control point.

Figure 9.17 presents the hydrologic states of the three different flows at the control point CP17. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are almost same. There are no effects by SB EFS at the control point.

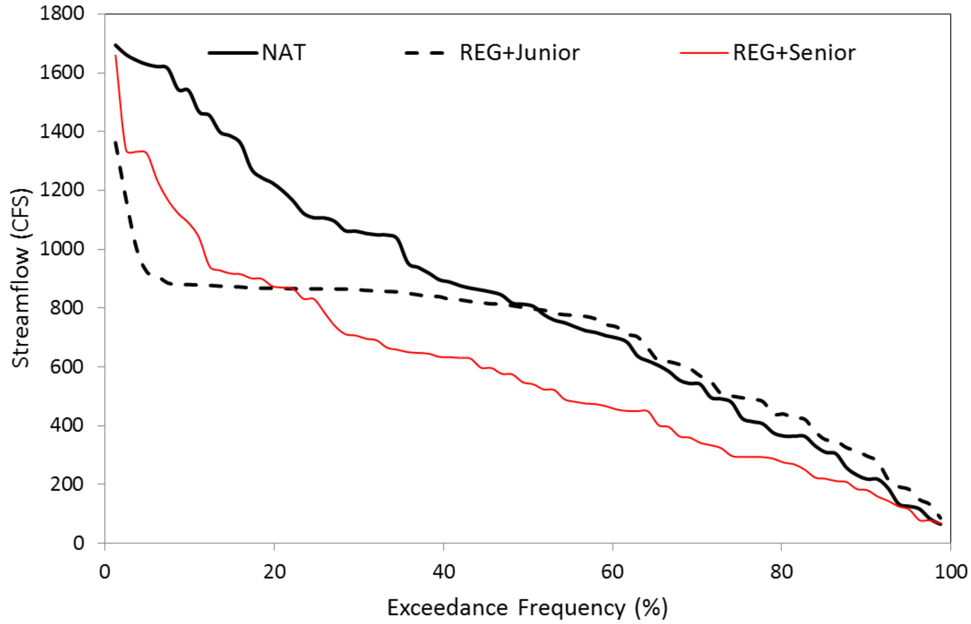



Figure 9.16 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point C38461

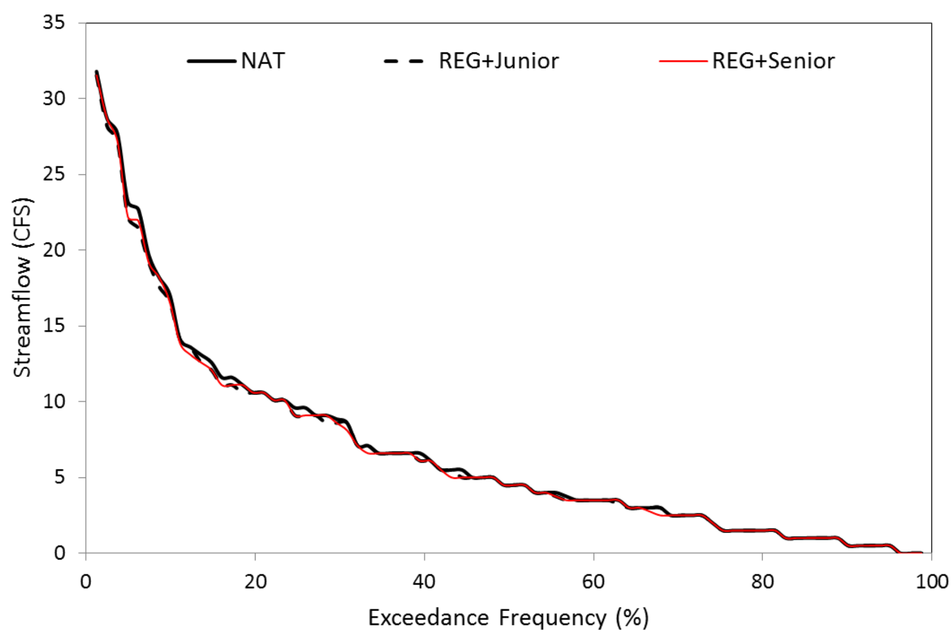



Figure 9.17 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP13

Figure 9.18 presents the hydrologic states of the three different flows at the control point CP14. The flow duration curves of both the regulated flows are totally different from the naturalized flows, but both are also different. This shows that SB3 EFS makes the flow regimes of regulated flow with a senior priority more similar to the naturalized flow.

Figure 9.19 presents the hydrologic states of the three different flows at the control point CP15. The flow duration curves of both the regulated flows are totally different from the naturalized flows, but both are also different. This shows that SB3 EFS makes the flow regimes of regulated flow with a senior priority more similar to the naturalized flow.

Figure 9.20 presents the hydrologic states of the three different flows at the control point P382411. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are almost same. This means that there are a few water rights at the control point and other upstream control points.

Figure 9.21 presents the hydrologic states of the three different flows at the control point CP28. SB3 EFS with a senior priority makes the flow regime of the regulated flow much closer to the naturalized flows than the regulated flow with a junior priority at the control point. This attributes that the timing of Medina Lake release is changes to meet the EFS at the downstream control points.

Figures 9.22 and 9.23 present the hydrologic states of the three different flows at the control points CP29 and CP32, respectively. SB3 EFS with a senior priority makes the flow regime of the regulated flow much closer to the naturalized flows than the regulated flow with a junior priority at the control points like the control point CP28. This attributes that the flow regime at the control point CP 28 directly influences the flow regime at the control points CP29 and CP32.

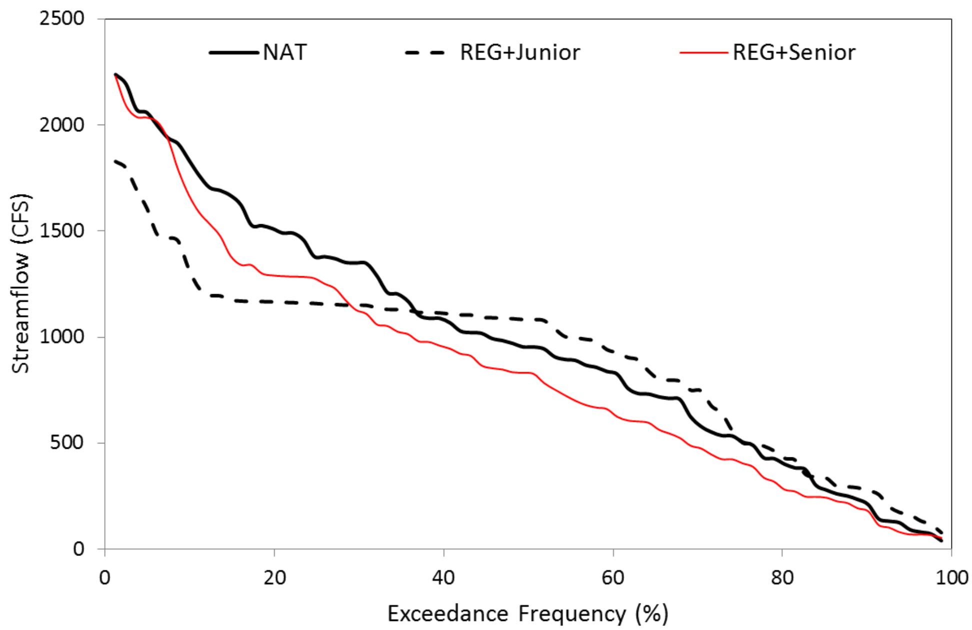



Figure 9.18 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP14

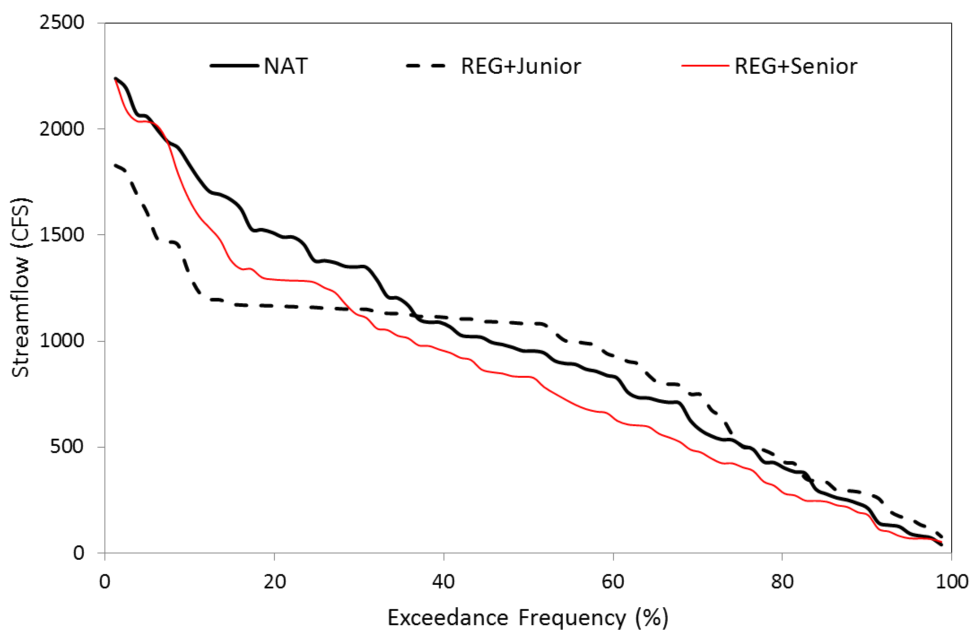



Figure 9.19 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP15

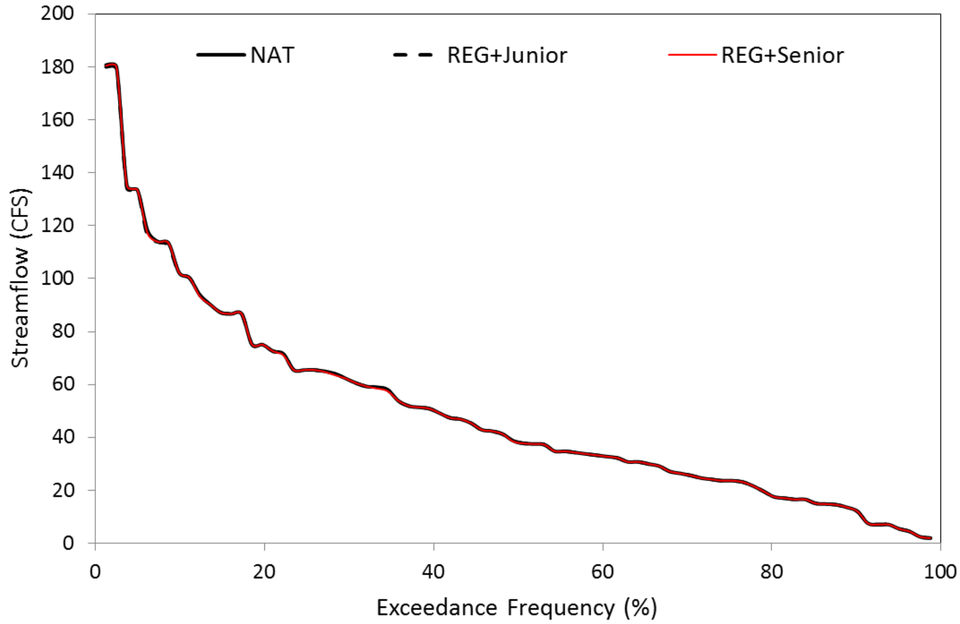



Figure 9.20 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point P38241

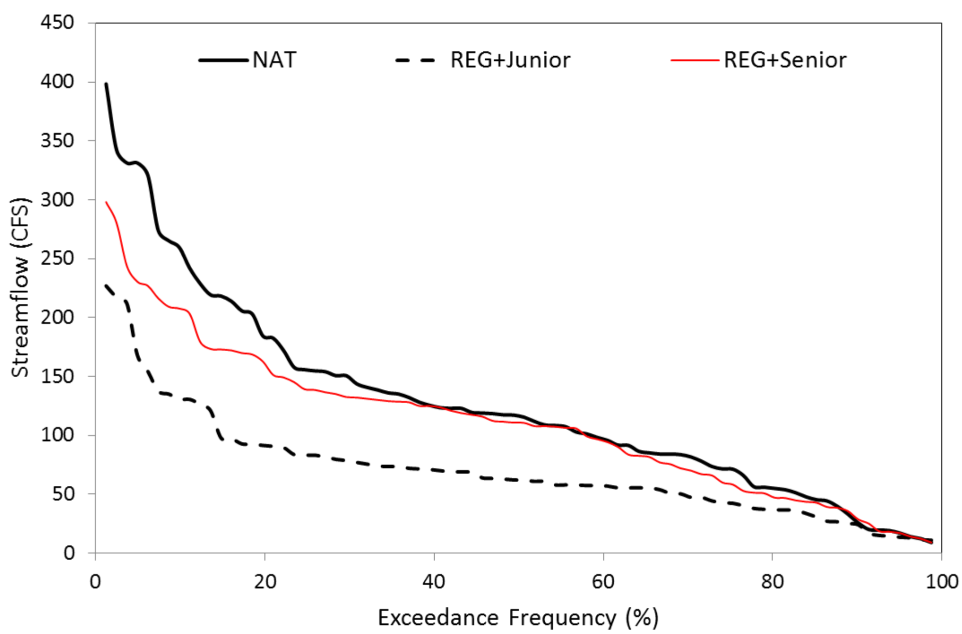



Figure 9.21 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP28

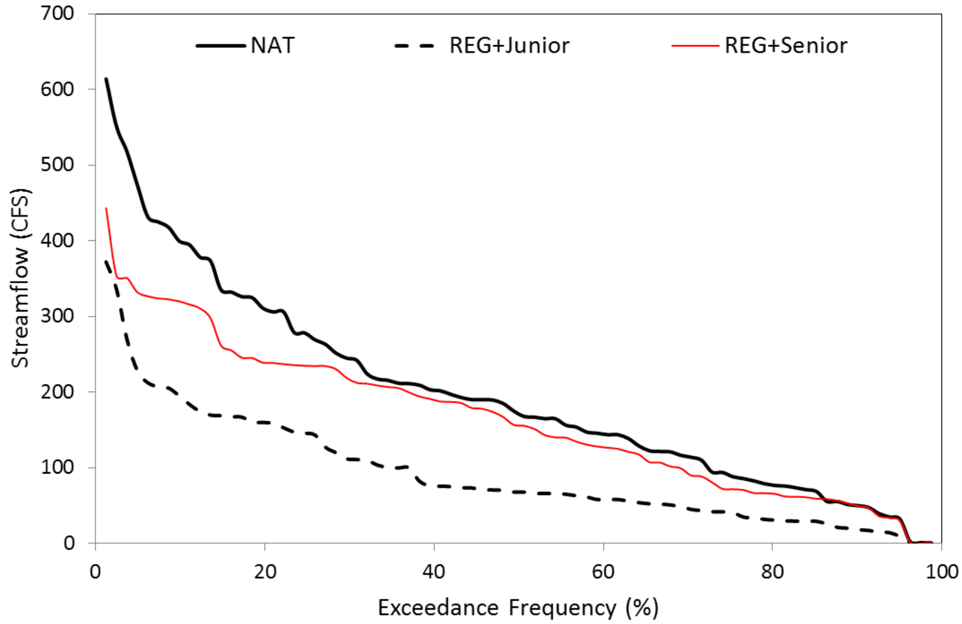



Figure 9.22 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP29

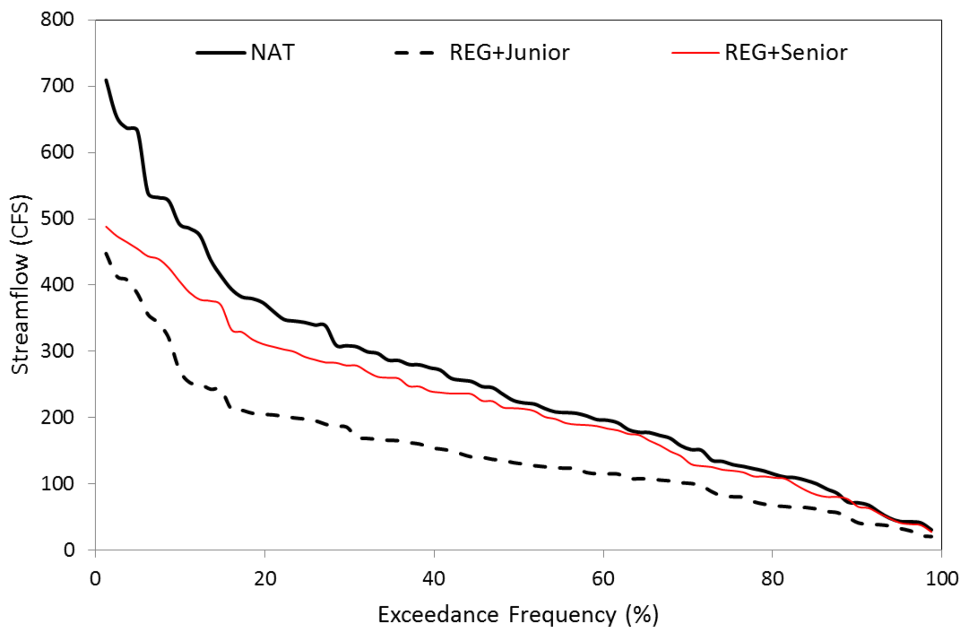



Figure 9.23 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP32

Figure 9.24 presents the hydrologic states of the three different flows at the control point CP35. The flow duration curves of both the regulated flows are very similar to the naturalized flows, and both are almost same. This is because there are a few water rights at the control point and other upstream control points.

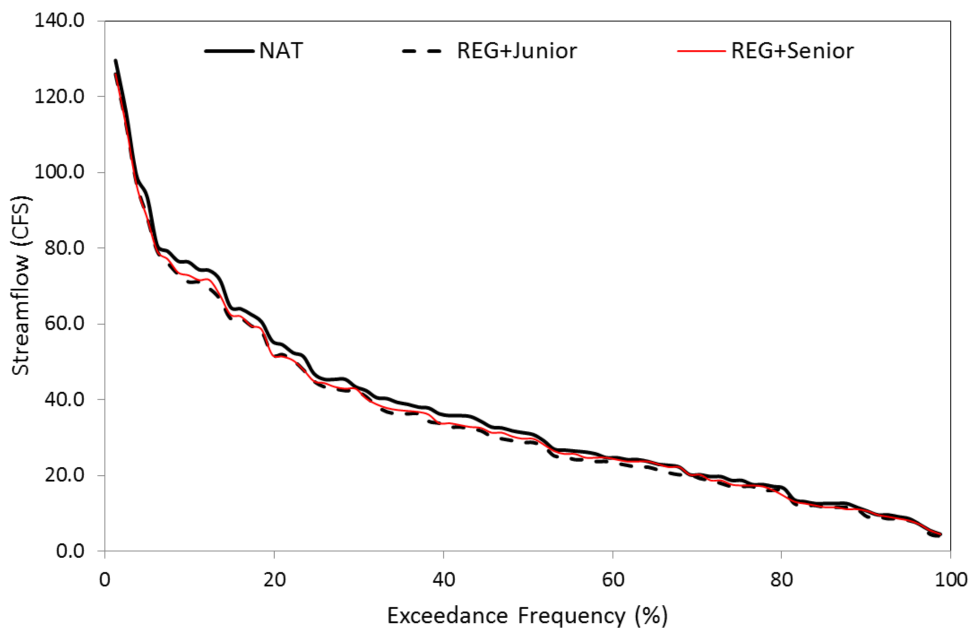



Figure 9.24 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP35

Figure 9.25 presents the hydrologic states of the three different flows at the control point CP37. SB3 EFS with a senior priority improves the flow regime of the regulated flow much closer to the naturalized flows than the regulated flow with a junior priority at the control point. The operation rule of Medina Lake by the EFS with a senior priority results in this alteration of the regulated flows at the control point like the control points, located upstream of the control point CP37.

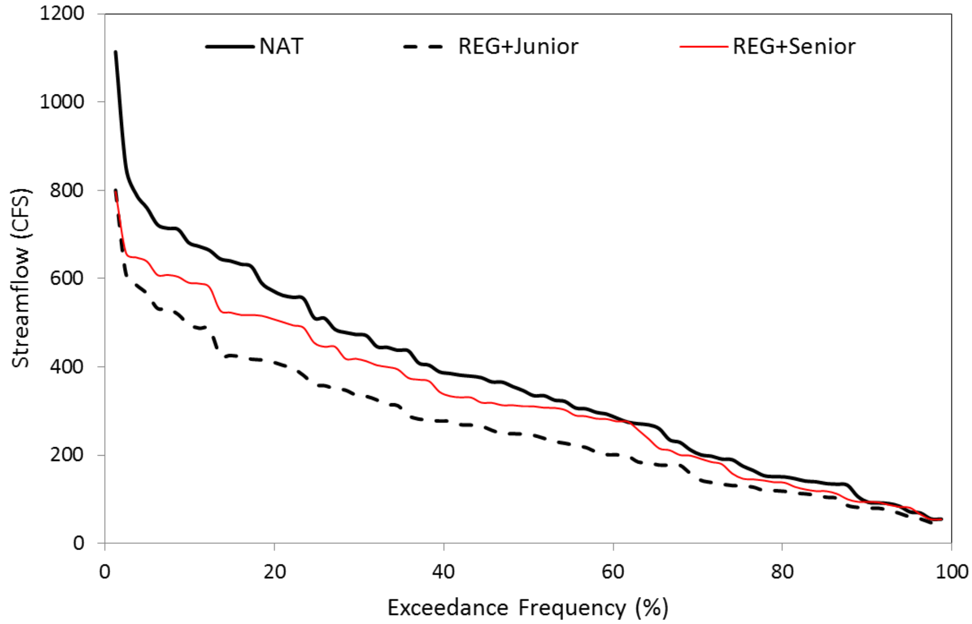



Figure 9.25 Annual Median Flow Duration Curves (NAT: Naturalized flow, REG+Junior: Regulated flow under EFS with a junior priority, REG+Senior: Regulated flow under EFS with a senior priority) at the Control Point CP37

# CHAPTER X
# SUMMARY AND CONCLUSIONS

The WRAP/WAM modeling system, as well as many other river/reservoir system management models reported in the literature, simulate system behavior under specified sets of conditions to analyze strategies for flood control, water supply, hydropower generation, navigation, recreation, and maintenance of environmental flows. Naturalized or otherwise homogeneous sequences of river flows are fundamental input required for these river/reservoir system models. The river flow input datasets capture the hydrologic characteristics of a river basin including severe multiple-year droughts, major floods, and the full range of more normal flow fluctuations. Incorporation of environmental flow considerations in river system management and associated modeling has been growing in importance in recent years in Texas and throughout the world.

Results and conclusions regarding the main modeling and analysis tasks covered in the preceding chapters of this dissertation are summarized in this final chapter. The dissertation research combines databases and computational techniques provided by the Water Rights Analysis Package (WRAP), Texas Water Availability Modeling (WAM) System, Soil and Water Assessment Tool (SWAT) modeling system, and National Water Information System (NWIS) to investigate and improve capabilities for developing and analyzing long sequences of homogenous river flows at multiple sites in major river/reservoir systems. The research investigates: (1) methods for developing naturalized or otherwise homogenous river flows representing specified conditions of basin development for input to models for simulating river/reservoir system operations and (2) characteristics of observed, naturalized, and simulated regulated river flows of relevance to water management and modeling thereof.

SWAT is used for a variety of purposes in this dissertation research. Alternative SWAT calibration strategies are investigated. SWAT results with and without calibration are compared for case study river systems. Other methodologies are combined with the SWAT and WRAP/WAM modeling systems to perform various tasks involved in developing naturalized flow datasets and analyzing flow characteristics. Alternative naturalized flow datasets are incorporated in the three case study WRAP/WAM models (called WAMs) for the Sabine, Neches, and Guadalupe and San Antonio (GSA) River Basins. The WRAP/WAM simulation studies performed in the research focus on environmental flow standards and their effects on regulated and unappropriated flows as well as on developing naturalized flow input datasets.

## 10.1 Infilling Missing Naturalized Flows Using the SWAT Model

Sequences of naturalized monthly flows at all primary control points covering a specified period-of-analysis are a necessary component of the input dataset for a WRAP simulation. The naturalized monthly flows in the WAM System were developed primarily by adjusting observed flows at USGS gauging stations to remove the effects of human activity. Gauge records often do not cover the entire model simulation period-of-analysis. Filling in gaps of missing data is a fundamental issue in developing naturalized flow datasets. The research investigated the use of SWAT and the maintenance of variance method, type 2, called MOVE2 (Hirsch, 1982) for filling in missing monthly naturalized flows. SWAT can be applied without MOVE2, MOVE2 can be applied without SWAT, or SWAT and MOVE2 can be applied in combination as proposed here.

The following strategy for applying SWAT and MOVE2 in combination to fill in gaps and/or extend sequences of monthly naturalized flows was developed and tested by application to the three case study WAMs. The monthly SWAT model synthesizes the monthly flow sequences for the period-of-analysis at a target site that has missing data. This model is calibrated with the available monthly flow data. The calibrated model generates the monthly flow sequence for a missing period at the site. The MOVE2 method firstly estimates population mean and variance of the flow sequence including a missing period at a target site. The method transfers the flow sequence for a missing period at a target site based on the flow sequence synthesized by the SWAT model and the estimated statistical parameters. The SWAT model plays the role of generating a highly correlated flow sequence at a gauged site. The MOVE2 method transfers the flow sequence for a missing period while preserving their statistical parameters at a target site. This means that the MOVE2 can transfer flow sequences to preserve the homogeneity at a target site.

The case studies test and demonstrate the performance of the method. The method is applied to monthly naturalized datasets at 17 control points for the three WAMs. The assumed missing periods are 18 years (1981-1998) for the Sabine WAM, 16 years (1981-1996) for the Neches WAM, and 14 years (1976 -1989) for the GSA WAM, respectively. The validity and accuracy of the method are evaluated by the Nash-Sutcliff efficiency (NSE) between the infilling naturalized data and naturalized flow dataset at the control points and by the comparison of flow duration curves for the assumed missing periods.

The following conclusions are derived from the case studies:

- The performances of a proposed method (the combination of the SWAT model and MOVE2 method) for infilling missing data are satisfactory in the evaluation by NSE at the 16 control points except for the control point CP05 in the Guadalupe River Basin. However, the method considerably improves NSE values from -3.03 to 0.48 as compared to applying only the synthesized flows sequences from the SWAT model at the control point CP05.
- The comparisons of the flow frequency metrics show that the infilled flow sequences for assumed missing periods have very similar hydrologic characteristics to the original flow dataset.
- The proposed method reliably fills in gaps of missing period while preserving homogeneity of flow sequences.
- If there are no highly correlated flow sequences around the target site that has a missing period, the method is an effective alternative.
- The proposed method can be applicable for developing new datasets or revising or extending existing datasets.

## 10.2 Refinement of Methods for Developing Naturalized Flows at Ungauged Sites Based on Flows at Gauged Sites

The correction factor K and an exponent $\phi$ of Equation 2.9 was added to the conventional equation of drainage area ratio method to remove or reduce the transfer errors when drainage ratios are less than 0.3 or more than 1.5. A new method to get representative K and $\phi$ for a basin is introduced in this research. Linear regression equations without intercept are developed based on two monthly naturalized flow sequences from control point pairs, and then K and $\phi$ are optimized from the assumption that drainage ratios with K and $\phi$ are equal to slopes (B) of the linear equations.

The reasons why a regional statistical method would generate transfer errors are revealed based on statistical concepts in this research. A new approach to select statistical parameters is suggested to address this issue on the method.

The performances of both the proposed methods are evaluated by the NSE between the developed flow data and naturalized flow dataset at the same control points. The following conclusions are derived from the case studies:

- The drainage area ratio (DAR) without a correction factor K and an exponent $\phi$ leads to 24 unsatisfactory (NSE below 0.5) performances and 5 unacceptable (negative value of NSE) performances.
- But, the DAR with K and $\phi$, derived from a new method in this research, results in only 2 unsatisfactory performances out of 357 performances in total.
- The new method is simple to implement and can be an additional option in the WRAP model.

In the regional statistic method, the performances by a new approach and existing approach are very similar, if statistical parameters have relatively strong linear relationship with regional variables like the Sabine and Neches WAM. However, if not, the new approach tends to enhance the performance of the regional statistical method for flows in the GSA and Trinity WAMs.

## 10.3 Disaggregation of Monthly to Daily Naturalized Flows Using the SWAT Model

The daily WRAP simulation model needs daily flow patterns for disaggregation of monthly naturalized flows to daily while preserving the monthly volumes. The SWAT models are developed to synthesize the daily flow patterns at all relevant control points for the three WAMs. The models are calibrated alternatively with two different available datasets: (1) WAM monthly naturalized flow datasets for periods-of-analysis and (2) USGS daily recorded flow data for un-impacted periods (1951-1960). Each of these datasets have pros and cons in the daily SWAT model calibration.

Two different daily naturalized flow sequences, disaggregated based on two different daily flow patterns that are synthesized by the two calibrated SWAT models, are evaluated by the following four methods: NSE, flow frequency metric, DHRAM (IHA), and annual median flow duration curves. These four methods represent streamflow timing, flow regime, hydrologic characteristics, and overall hydrologic state of a flow, respectively.

The daily flow sequences, used for the comparison of the disaggregated daily naturalized flows, are the USGS daily recorded data for un-impacted periods. The selected un-impacted periods are commonly before 1960. More appropriated disaggregated daily flow sequences are selected for daily WRAP models through the four different evaluations.

The case studies support the following conclusions:

- SWAT models, calibrated with either monthly naturalized or daily recorded flows are able to simultaneously synthesize daily flow patterns that are used for the daily WRAP model at multiple-sites.
- More appropriate daily synthesized flow sequences for the daily WRAP model can be selected through a systematic evaluation strategy developed in this research, depending on basin characteristics such as soil and land cover, rainfall patterns, and interaction between surface and groundwater.
- In this research, the SWAT models, calibrated with USGS daily recorded flows for un-impacted periods are more appropriate for the Sabine and Neches WAMs,

representing conditions of high rainfall, forested watershed, minimal surface/groundwater interactions, and relatively low population densities.

- The SWAT model, calibrated with monthly naturalized flows for period-of-analysis is more appropriate for the GSA WAM, representing conditions of lower rainfall, major surface/groundwater interactions, and much higher population densities.
- The combination of the SWAT model and the new systematic evaluation strategy can be an effective approach for disaggregating monthly naturalized flow to daily.

### 10.4 Evaluating Environmental Flow Standards

The Dundee Hydrological Regime Alteration Method (DHRAM), which incorporates the Indicators of Hydrologic Alteration (IHA) methodology, assesses the hydrological alterations of daily river flow sequences between user-defined impacted and un-impacted periods. USGS recorded flows are divided into the two periods before and after dam construction and associated initial reservoir storage that is considered to be the most significant point-specific human influence for the DHRAM analysis. Naturalized flows are theoretically un-impacted flows, and regulated flows are impacted flows in the WAM system. The hydrological alterations between both the flows at the same sites are also evaluated by the DHRAM. If there are the similarities between the two results of the DHRAM analyses at the same site, the capabilities of the WRAP model are employed to quantify the alterations of river flow regime under SB3 environmental flow standards.

SB3 environmental flow standards (EFS) do not impact existing water rights because these standards are assigned junior priorities. The environmental flow standards were established to preserve the current flow regimes from future water right applicants. However, for purposes of comparison, alterative daily WRAP simulations are performed with the priority of the EFS set as the most senior versus most junior water rights in the WAMs.

The daily WRAP simulation model computes sequences of regulated and unappropriated flows based on naturalized flow datasets for the hydrologic period-of-analysis. The impacts on future water rights by EFS are evaluated by comparing unappropriated flows at a control point with and without the EFS. Unappropriated flow frequency metrics with and without EFS are used for the evaluation.

Also as another comparative evaluation, the alterations between naturalized and regulated flows are assessed with the EFS assigned the most senior versus junior priorities. The alterations between alternative flows generated by the WRAP simulation model with the different EFS priorities are compared by two different methods, the DHRAM method and annual mean flow duration curve. The control points where SB3 EFSs were incorporated are chosen for the comparison of flow alterations because flow alterations at the control points with EFSs are typically more apparent than at other control points.

The case studies lead to the following conclusions:

- The results of the DHRAM analyses based on USGS recorded daily flows divided into the un-impacted and impacted periods are closely similar to the results based on the naturalized and regulated flows for periods-of-analysis at the same sites for the Sabine and Neches WAMs. However, there are differences in the two comparative results of the DHRAM analysis for the GSA WAM. This is apparently attributed to return flows from municipal ground water use and the Medina Lake operation.
- These studies indicate that the alteration of river flow regime under SB3 environmental flow standards can be evaluated based on naturalized, regulated, and unappropriated flows from the WRAP model simulations.
- Unappropriated flows are slightly decreased by SB3 environmental flow standards at most control points in the three WAMs.
- Although the environmental flow standards have most senior priorities than all other water rights, these cannot contribute to recover the flow regimes of the regulated flows to the naturalized flows in the Sabine and Neches WAMs. This is because the environmental flow targets are engaged based on the regulated flows, and the volumes of the regulated flows considerably decrease than the naturalized flows due to consumptive water rights, such as diversions and refilling reservoirs.
- The environmental flow standards with the most senior priority significantly contribute to restore the flow regimes of the regulated flows to the naturalized flows

in the GSA WAM. This is attributed to relatively a few consumptive water rights than other two basins. More than 30 percent of the total authorized consumptive diversions from the two rivers and their tributaries are located below their confluence (Wurbs *et al.*, 2014c). Water rights for hydropower, modeled as diversions with 100% return flows, account for 83.1 percent of the total diversions (Wurbs *et al.*, 2014c).

The results of this research can provide feedback regarding the existing SB3 environmental flow standards and useful information for establishing environmental flow standards in other river basins. The research can contribute to expanding and refining WRAP/WAM modeling capabilities to support addressing environmental flow considerations in river system management while meeting growing water uses.

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